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DTIC

# Tunnel Closure Experiment 1997 Test Programme

## Core Logging and Laboratory Tests on Diamond Drilled Holes at Jerntoppen

Post-Final Rep

923033-13

8 June 1998





NGI

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# Tunnel Closure Experiment
# 1997 Test Programme

## Core Logging and Laboratory Tests on Diamond Drilled Holes at Jerntoppen

Post-Final Rep

923033-13 | 8 June 1998

**Client:** **Waterways Experiment Station**

Contact person: Will McMahon
Contract reference: N68171-97-C-9005

**For the Norwegian Geotechnical Institute**

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# Summary

The Tunnel Closure Experiment - 1997 Test Programme included seven tunnel response tests and two tunnel portal tests. The tests were carried out in August 1997 (eight tests) and September 1997 (one test) in AS Sydvaranger's open pit mine at Bjørnevatn, Kirkenes, Norway.

Rock cores were collected for each of the tunnel response tests previous to drilling of the large diameter boreholes for bomb emplacements.

The rock cores have been analysed with respect to rock type, Rock Quality Designation (RQD, apparent and true), joint frequency, Joint Alteration Factor ($J_a$), Joint Roughness Factor ($J_r$), joint filling, joint angle related to the core, crushed core and core loss.

Laboratory tests on specimens from the rock cores have been carried out. The tests include pressure-wave velocity ($V_P$), shear-wave velocity ($V_S$), density, Uniaxial Compressive Strength (UCS), Young's modulus (E-modulus) and Poisson's ratio.

This report gives the results of the core logging and the results of the laboratory tests.

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# 1 INTRODUCTION

The Tunnel Closure Experiment - 1997 Test Programme included seven tunnel response tests and two tunnel portal tests. The tests were carried out in August 1997 (eight tests) and September 1997 (one test) in AS Sydvaranger's open pit mine at Bjørnevatn, Kirkenes, Norway. The locations of the tunnel response tests at the site Jerntoppen tunnel are shown in Figure 1.

Rock cores were collected for each of the tunnel response tests previous to drilling of the large diameter boreholes for bomb emplacements. The locations of the diamond drilled boreholes were almost similar to the locations of the large diameter boreholes, *i.e.* similar start point, similar direction, but the diamond drilling was generally stopped approx. 1 m above the tunnel ceiling. The diameter of the rock cores was 35 mm.

This report gives the results of the core logging and the results of the laboratory tests on specimens collected from the cores. Laboratory tests include pressure-wave velocity ($V_P$), shear-wave velocity ($V_S$), density, Uniaxial Compressive Strength (UCS), Young's modulus (E-modulus) and Poisson's ratio.

# 2 CORE LOGGING

## 2.1 General

Seven boreholes have been analysed. Table 1 summarises the boreholes.

*Table 1 Diamond drilled holes at Jerntoppen*

| Borehole No. | Core length | Location |
|---|---|---|
| 97-1 | 11.0 m | Jerntoppen adit extension |
| 97-2 | 20.0 m | Jerntoppen adit extension |
| 97-3 | 20.0 m | "Old" Jerntoppen tunnel |
| 97-5 | 15.5 m | Jerntoppen adit extension |
| 97-6 | 17.0 m | Jerntoppen adit extension |
| 97-7 | 14.5 m | Jerntoppen adit extension |
| 97-8 | 8.2 m | Jerntoppen adit extension |

The rock cores have been analysed with respect to rock type, Rock Quality Designation (RQD, apparent and true), joint frequency, Joint Alteration Factor ($J_a$), Joint Roughness Factor ($J_r$), joint filling, joint angle related to the core, crushed core and core loss. Reference to the Q-system parameters included in the analysis is given in Figure 9.

The true RQD, which is a measure of the degree of natural jointing, is supplemented by the apparent RQD. The apparent RQD also includes cracks which have been induced by previous blasting and by the diamond drilling itself. It should be noted that it has been difficult to determine the true RQD and joint frequency in sections which include crushed core.

## 2.2 General geological description based on the core logging

The main rock type in the boreholes is a fine grained, dark grey or greenish gneiss usually containing hornblende and biotite. There are random bands of quartz veins. Some quartz veins have a thickness of a few centimetres while others are only a few millimetres thick. The rock has generally a wavy foliation due to small scale folding. Predominant RQD values are in the range 90-100%.

The following joint sets have been identified:

Foliation joints, angle 70-80° .
Joints, angle 10-30°.
Joints, angle 30-45°.

The angles given above and in the following, are generally the smallest angle between the joint and the core.

The frequency of the foliation joints seems to be dependent on the rock type to some extent. The angle is mostly 70-80°, but varies due to folding between 60° and 90°. In the cores, several breakage's per meter parallel to the foliation have been registered, but few of these are natural joints. The spacing for the foliation joints in the range 0.75-2 m seems to be realistic. The joints are undulating due to small scale folding, occasionally rough, and mainly calcite and to a less extent biotite coating, have been observed. Rust stains have been registered, but there is no clay coating on foliation joints.

The joints with angles in the range 10-30° are rough and mostly slightly undulating. Mostly, they have a coating of calcite and/or rust. In sections, in some of the boreholes, several of these joints per meter have been found, and since they have an acute angle to the borehole axis the spacing is assumed to be small. Based on survey in the tunnel below we assume that only a few of these joints are pervasive, and the majority are only short cracks. A realistic spacing is therefore estimated to be 1-2 m.

The third joint set has angles in the range 30-40°. The majority is rough and undulating to planar. They also have mineral coating; calcite, biotite and rust stains. From core logging observations these joints seem to be short (a few meters) and the spacing is in the range 0.5-2 m.

## 2.3 Detailed geological description of each borehole

**Borehole 97-1** (Figure 2). The rock is a grey biotite gneiss. There is significant blasting damage in the upper two meters of the borehole, RQD below two meters is 95-100% and joint frequency is largely 1-5 per meter. The main joint set has an angle of 45° and has often calcite or rust coating. Foliation joints are rare, but the foliation has an angle of approx. 70°. Some joints with angle 20-30° without coating have also been found.

**Borehole 97-2** (Figure 3). The rock in this borehole is a grey biotite gneiss. The whole borehole shows a rather low apparent RQD, probably due to blast damage. True RQD is normally 100%, and the joint frequency is 1-4 per meter. Predominant joints have an acute angle related to the core and they have calcite coating or rust stains. Foliation joints with angle 70-80° may have similar coating. In addition, some joints with angle 30-45° have been found.

**Borehole 97-3** (Figure 4). The rock in this borehole is a grey to greenish biotite gneiss. At about 11 m depth there is a distinct white coloured band. The whole borehole shows a rather low apparent RQD number, due to blast damage or induced by the core drilling. True RQD is normally in the interval 90-100%, and the joint frequency is 1-5 per meter. The predominant joint set has angle 60° and calcite coating or rust stains. Also foliation joints with angle 10-30° may have such coating. In addition, some joints with angle 30-45° with the same coating have been found.

**Borehole 97-5** (Figure 5). The rock in the upper part of the borehole (0-3.0 m) is a grey biotite gneiss. The lower part of the borehole (4.0-15.5 m) is a greenish amphibolitic gneiss. There is significant material disking, especially at depth 4.0 - 15.5 m. The joint frequency is 0-1 per meter at depth 0-5 m where RQD is 100%. At depth 5-15 m RQD is 50-100%. The major joint set has angle 70-90° and often biotite coating. Also, some foliation joints with angle 30-45°, and some joints with angle 20° have been registered.

**Borehole 97-6** (Figure 6). The rock in this borehole is mainly grey biotite gneiss. The joint frequency varies between 1 and 3 per meter and RQD varies between 60% and 100% in the upper part of the borehole. In the lower part of the borehole the joint frequency is largely 1-5 per meter and RQD varies between 40% and 100%. The major joint set has angle 70-90° and coating of biotite, calcite or rust stains is common. A few foliation joints with angle 30-45° with rust stains or calcite have been registered.

**Borehole 97-7** (Figure 7). The rock in this borehole is a grey biotite gneiss with relatively few joints. RQD is normally 100%, and the joint frequency is largely 1-2 per meter in the whole borehole. The predominant joint set has angle 30-45° and calcite coating or rust stains. In addition, some joints with angle 30-45°

with the same coating have been observed. Only one foliation joint has been registered in this borehole.

**Borehole 97-8** (Figure 8). The rock in this borehole is mainly grey biotite gneiss alternating with grey/greenish biotite gneiss. There is some material disking at depth 6.0-8.0 m. The joint frequency varies between 1 and 5 per meter in the upper two meters of the borehole and RQD is 60-80%. The joint frequency is 1-3 per meter in the lower part of the borehole and RQD is 80-100%. The major joint set has angle 20-30°. The coating is mainly rust stains and occasionally biotite or calcite. A few joints with angle 30-60° with biotite and calcite coating have been registered.

## 3 LABORATORY TEST

Specimens for laboratory test are generally collected from the deepest two meters of the cores. Prior to the uniaxial compression testing, P-wave and S-wave measurements were carried out. Unconfined compression tests and photos of the specimens are shown in Figures 10.1-10.33 and Figures 11.1-11.4 respectively.

A summary of the test results is given in Table 2. P-wave velocities range from 5,001 to 5,819 m/s with a mean value of 5,401 m/s. S-wave velocities range from 2,919 to 3,805 m/s with a mean value of 3,324 m/s.

Density varies between 2,724 and 3,573 $kg/m^3$ with a mean value of 3,035 $kg/m^3$.

Uniaxial compressive strength varies between 85 MPa and 446 MPa with a mean value at 248 MPa. Young's modulus varies between 23.4 GPa and 80.1 GPa with a mean value of 55.4 GPa. Young's modulus was taken as secant modulus between 10% and 40% of the first 100 MPa (or lower for a few specimens with UCS lower than 100 MPa).

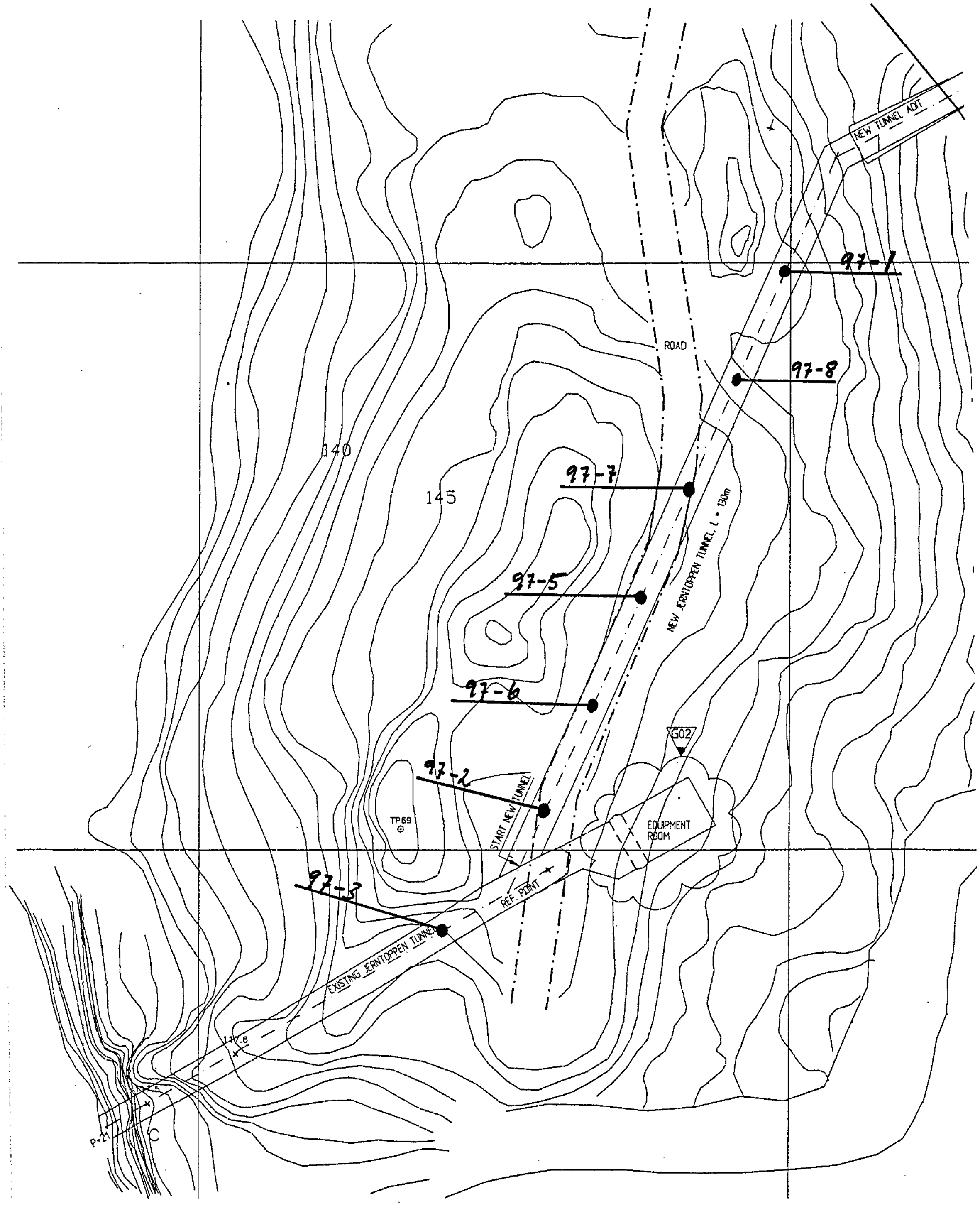
The measured mean value for Poisson's ratio is 0.30. Poisson's ratio varies between 0.18 and 0.48. Poisson's ratio was calculated between 60% and 90% of the first 100 MPa of each specimen for boreholes 97-1 and 97-2. For the other boreholes Poisson's ratio was calculated between 10% and 40% of the first 100 MPa.

*Table 2* *The results of the laboratory tests*

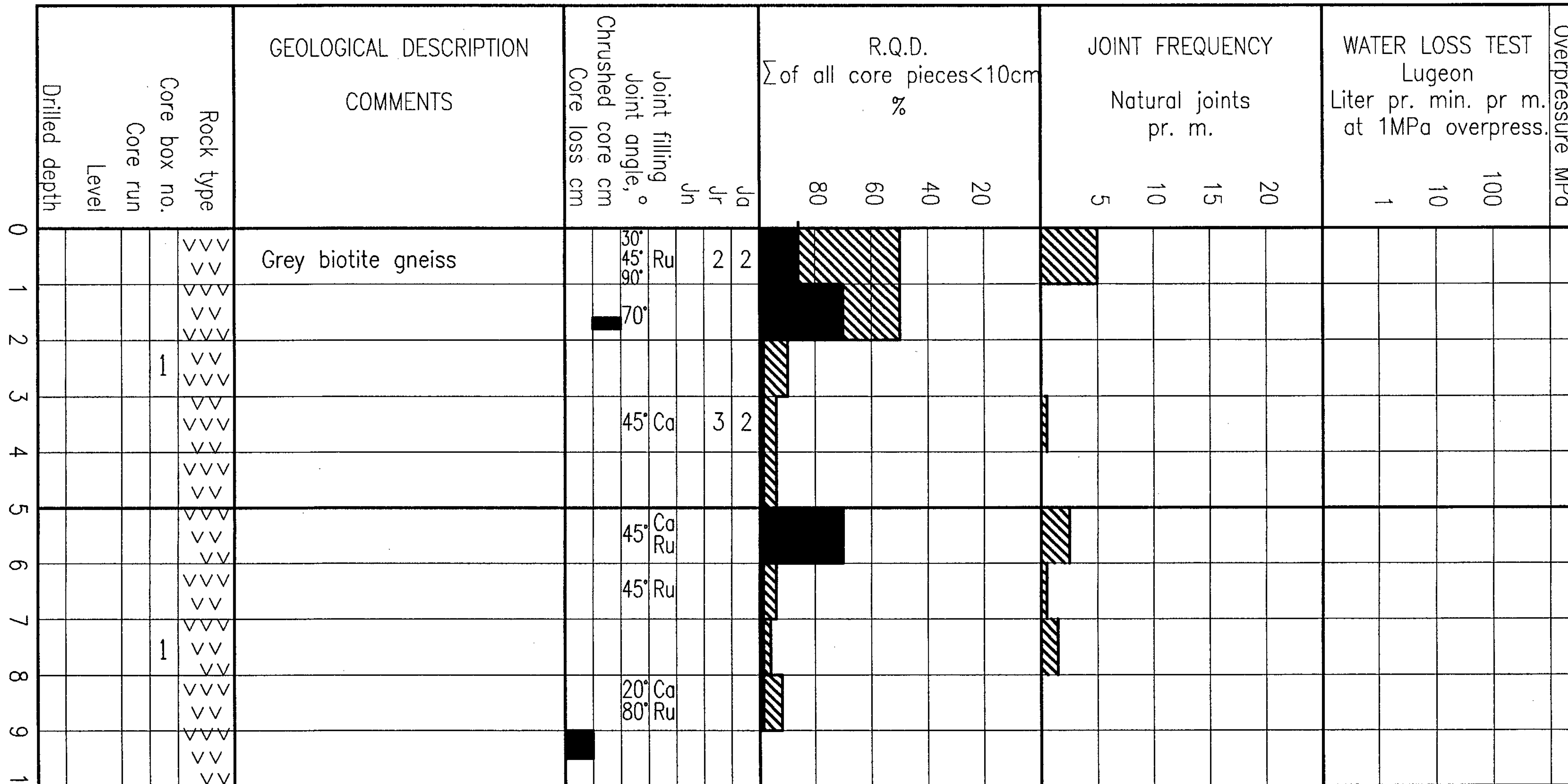
| Test | Sample | Depth | Length | Diameter | Vp | Vs | Density | UCS | E mod | Poisson |
|---|---|---|---|---|---|---|---|---|---|---|
| no | no | m | mm | mm | m/s | m/s | kg/m3 | MPa | GPa | ratio |
| UCT352/1 | 97/1-1 | 7.11 | 84.34 | 35.05 | 5365 | 3501 | 3502 | 361.70 | 80.06 | 0.306 |
| UCT353/2 | 97/1-2 | 9.19 | 83.70 | 35.08 | 5449 | 3459 | 3517 | 445.83 | 78.97 | 0.413 |
| UCT354/3 | 97/1-3 | 9.28 | 83.71 | 35.07 | 5471 | 3805 | 3422 | 357.27 | 75.29 | 0.43 |
| UCT355/4 | 97/1-4 | 10.38 | 84.05 | 34.86 | 5388 | 3445 | 3573 | 269.37 | 73.58 | 0.343 |
| UCT356/5 | 97/1-5 | 10.56 | 84.35 | 34.95 | 5339 | 3361 | 3501 | 306.80 | 74.1 | 0.361 |
| maximum | maximum | | 84.35 | 35.08 | 5471 | 3805 | 3573 | 445.83 | 80.06 | 0.43 |
| mean | average | | 84.03 | 35.00 | 5402 | 3514 | 3503 | 348.19 | 76.40 | 0.37 |
| minimum | minimum | | 83.70 | 34.86 | 5339 | 3361 | 3422 | 269.37 | 73.58 | 0.31 |
| UCT357/6 | 97/2-1 | 17.02 | 83.46 | 35.02 | 5197 | 3371 | 3139 | 376.50 | | |
| UCT358/7 | 97/2-2 | 17.10 | 84.06 | 34.85 | 5538 | 3479 | 3130 | 337.26 | 76.79 | 0.257 |
| UCT359/8 | 97/2-3 | 19.15 | 83.46 | 34.87 | 5455 | 2939 | 3283 | 290.87 | 66.13 | 0.355 |
| UCT360/9 | 97/2-4 | 19.39 | 84.09 | 34.86 | 5689 | 3587 | 3354 | 197.93 | 68.83 | 0.304 |
| UCT361/10 | 97/2-5 | 19.50 | 82.87 | 34.90 | 5532 | 3447 | 3241 | 246.88 | 75.42 | 0.253 |
| maximum | maximum | | 84.09 | 35.02 | 5689 | 3587 | 3354 | 376.50 | 76.79 | 0.36 |
| mean | average | | 83.59 | 34.90 | 5482 | 3365 | 3229 | 289.89 | 71.79 | 0.29 |
| minimum | minimum | | 82.87 | 34.85 | 5197 | 2939 | 3130 | 197.93 | 66.13 | 0.25 |
| UCT362/11 | 97/3-1 | 10.70 | 82.86 | 35.04 | 5159 | 3196 | 2764 | 152.62 | 31.58 | 0.21 |
| UCT363/12 | 97/3-2 | 13.20 | 82.89 | 35.15 | 5266 | 2919 | 2724 | 85.02 | 23.42 | 0.298 |
| UCT364/13 | 97/3-3 | 17.44 | 82.92 | 35.02 | 5001 | 3153 | 2753 | 107.46 | 24.67 | 0.37 |
| UCT365/14 | 97/3-4 | 17.53 | 82.94 | 34.98 | 5039 | 3142 | 2755 | 99.29 | 24.01 | 0.18 |
| UCT366/15 | 97/3-5 | 17.71 | 82.90 | 35.09 | 5061 | 3251 | 2728 | 88.14 | 26.88 | 0.211 |
| maximum | maximum | | 82.94 | 35.15 | 5266 | 3251 | 2764 | 152.62 | 31.58 | 0.37 |
| mean | average | | 82.90 | 35.06 | 5105 | 3132 | 2745 | 106.51 | 26.11 | 0.25 |
| minimum | minimum | | 82.86 | 34.98 | 5001 | 2919 | 2724 | 85.02 | 23.42 | 0.18 |
| UCT367/16 | 97/5-1 | 14.14 | 83.24 | 34.67 | 5356 | 3083 | 2982 | 413.58 | 75.69 | 0.244 |
| UCT368/17 | 97/5-2 | 14.23 | 83.26 | 34.69 | 5317 | 3263 | 3013 | 362.63 | 41.26 | 0.22 |
| UCT369/18 | 97/5-3 | 14.82 | 83.85 | 34.53 | 5410 | 3448 | 3170 | 309.12 | 49.25 | 0.28 |
| UCT370/19 | 97/5-4 | 14.91 | 83.86 | 34.56 | 5341 | 3420 | 3157 | 353.61 | 54.86 | 0.293 |
| UCT371/20 | 97/5-5 | 15.16 | 83.95 | 34.50 | 5545 | 3144 | 3149 | 267.03 | 57.5 | 0.406 |
| maximum | maximum | | 83.95 | 34.69 | 5545 | 3448 | 3170 | 413.58 | 75.69 | 0.41 |
| mean | average | | 83.63 | 34.59 | 5394 | 3272 | 3094 | 341.19 | 55.71 | 0.29 |
| minimum | minimum | | 83.24 | 34.50 | 5317 | 3083 | 2982 | 267.03 | 41.26 | 0.22 |
| UCT372/21 | 97/6-1 | 10.46 | 83.76 | 35.22 | 5376 | 3149 | 2784 | 345.16 | 73.52 | 0.342 |
| UCT373/22 | 97/6-2 | 10.55 | 83.79 | 35.20 | 5448 | 3394 | 2858 | 123.40 | 51.72 | 0.277 |
| UCT374/23 | 97/6-3 | 11.18 | 83.84 | 35.10 | 5711 | 3598 | 3305 | 259.83 | 52.94 | 0.296 |
| UCT375/24 | 97/6-4 | 11.74 | 83.92 | 34.85 | 5366 | 3453 | 3147 | 424.50 | | |
| UCT376/25 | 97/6-5 | 11.83 | 83.80 | 34.83 | 5218 | 3139 | 2912 | 309.94 | 53.27 | 0.24 |
| maximum | maximum | | 83.92 | 35.22 | 5711 | 3598 | 3305 | 424.50 | 73.52 | 0.34 |
| mean | average | | 83.82 | 35.04 | 5424 | 3347 | 3001 | 292.57 | 57.86 | 0.29 |
| minimum | minimum | | 83.76 | 34.83 | 5218 | 3139 | 2784 | 123.40 | 51.72 | 0.24 |

*Table 2 (continued)*

| Test | Sample | Depth | Length | Diameter | Vp | Vs | Density | UCS | E mod | Poisson |
|---|---|---|---|---|---|---|---|---|---|---|
| no | no | m | mm | mm | m/s | m/s | kg/m3 | MPa | GPa | ratio |
| UCT378/27 | 97/7-1 | 13.25 | 82.86 | 34.87 | 5819 | 3603 | 2955 | 178.40 | 58.49 | 0.472 |
| UCT378/27 | 97/7-2 | 13.32 | 83.13 | 34.89 | 5702 | 3325 | 2820 | 319.60 | 65.63 | 0.184 |
| UCT379/28 | 97/7-3 | 13.64 | 83.10 | 34.85 | 5555 | 3208 | 2883 | 273.10 | 72.38 | 0.197 |
| UCT380/29 | 97/7-4 | 13.73 | 83.11 | 34.94 | 5418 | 3120 | 2936 | 205.74 | 65.39 | 0.241 |
| UCT381/30 | 97/7-5 | 13.82 | 83.12 | 34.95 | 5534 | 3079 | 2872 | 245.73 | 60.39 | 0.18 |
| maximum | maximum | | 83.13 | 34.95 | 5819 | 3603 | 2955 | 319.60 | 72.38 | 0.47 |
| mean | average | | 83.06 | 34.90 | 5605 | 3267 | 2893 | 244.51 | 64.46 | 0.25 |
| minimum | minimum | | 82.86 | 34.85 | 5418 | 3079 | 2820 | 178.40 | 58.49 | 0.18 |
| UCT382/31 | 97/8-1 | 7.00 | 84.08 | 35.17 | 5355 | 3284 | 2774 | 136.13 | 32.14 | 0.482 |
| UCT383/32 | 97/8-2 | 7.23 | 84.07 | 35.15 | 5368 | 3320 | 2811 | 97.99 | 36.17 | 0.323 |
| UCT384/33 | 97/8-3 | 7.70 | 83.91 | 35.13 | 5291 | 3367 | 2789 | - | - | - |
| UCT385/34 | 97/8-4 | 7.79 | 83.94 | 35.17 | 5402 | 3423 | 2757 | 95.56 | 35.98 | 0.373 |
| UCT386/35 | 97/8-5 | 7.88 | 83.92 | 35.14 | 5558 | 3456 | 2765 | 134.27 | 38.42 | 0.33 |
| maximum | maximum | | 84.08 | 35.17 | 5558 | 3456 | 2811 | 136.13 | 38.42 | 0.48 |
| mean | average | | 83.98 | 35.15 | 5395 | 3370 | 2779 | 115.99 | 35.68 | 0.38 |
| minimum | minimum | | 83.91 | 35.13 | 5291 | 3284 | 2757 | 95.56 | 32.14 | 0.32 |




| WES - TUNNEL CLOSURE EXPERIMENT | Report No. 923033-13 | Figure No. 1 |
|---|---|---|
| TUNNEL RESPONSE TESTS<br>Map of the site Jerntoppen<br>Locations of boreholes<br>Scale 1:1000 | Drawn by VK<br>Checked<br>Approved | Date 98-03-27<br>NGI |




R.Q.D. APPARENT RQD

F = Foliation Bi = Biotite
Ca = Calcite Ru = Rust

# WES – TUNNEL CLOSURE EXPERIMENT

Core logging

Borehole No. 97/1
Length: 0.0 – 10.0 m

| | | | |
|---|---|---|---|
| Report no. 923033–13 | | Fig. no. 2.1 | |
| Draw. GMB | | Date 21.04.98 | |
| Checked | | NGI | |
| Approved | | | |

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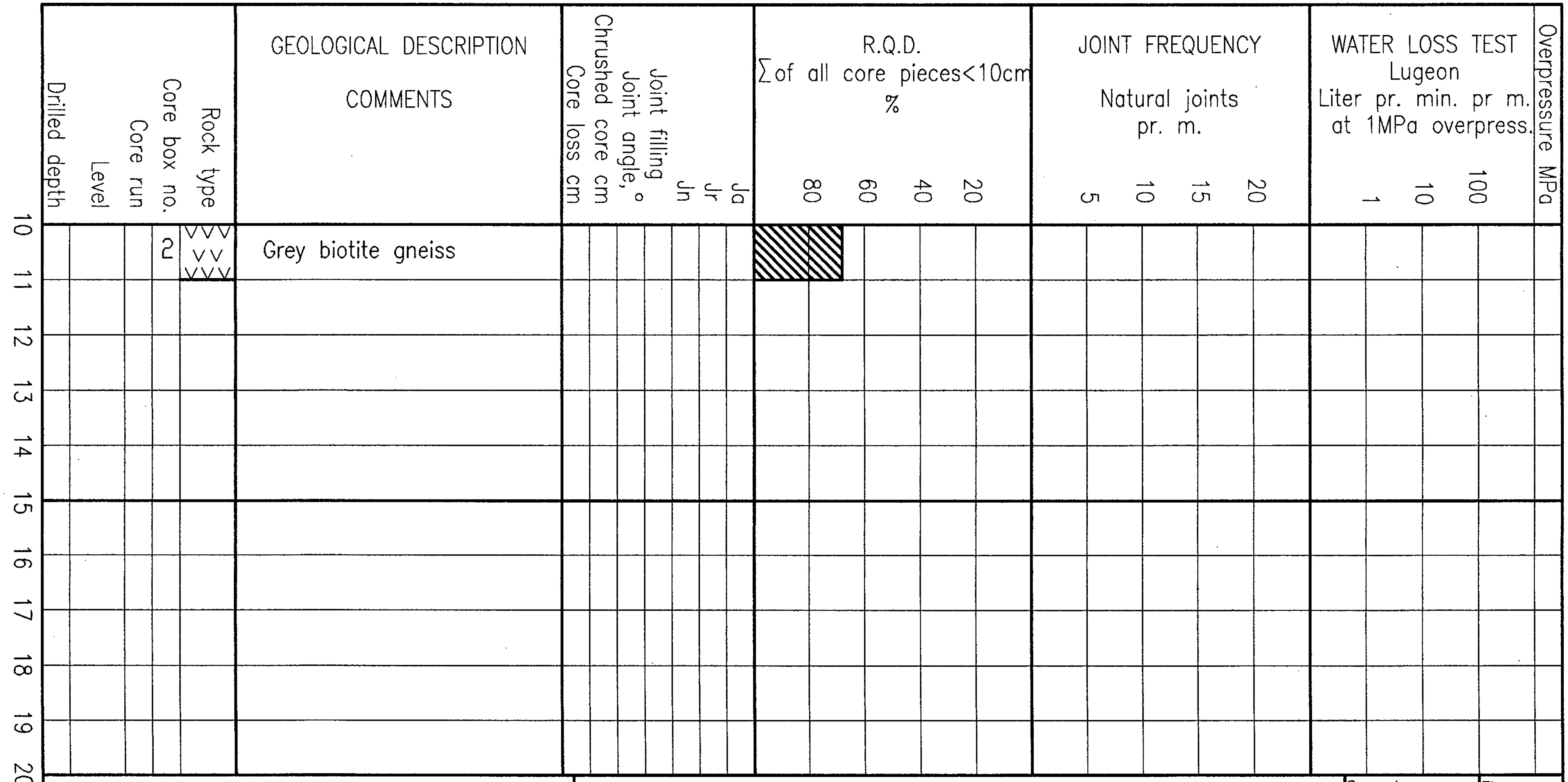


R.Q.D. | APPARENT RQD

F = Foliation  Bi = Biotite
Ca = Calcite  Ru = Rust

# WES – TUNNEL CLOSURE EXPERIMENT

Core logging

Borehole No. 97/1
Length: 10.0 – 11.0 m

| Report no. | Fig. no. |
|---|---|
| 923033–13 | 2.2 |
| Draw. GMB | Date 21.04.98 |
| Checked | NGI |
| Approved | |

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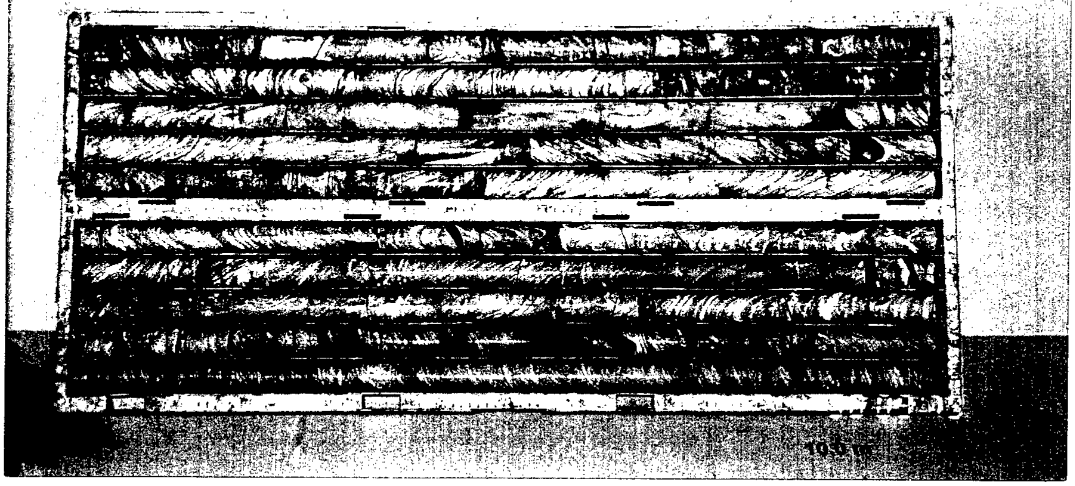
JERNTOPPEN

97/1

0.0-11.0 m

0.0 m

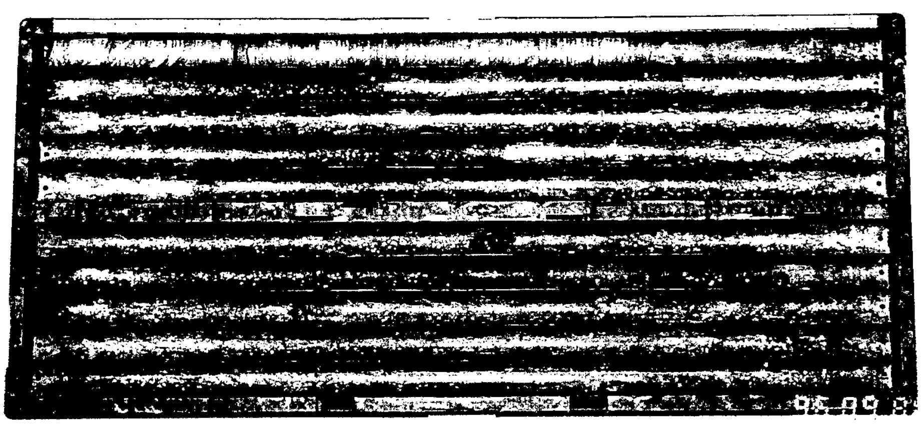


JERNTOPPEN

97/1

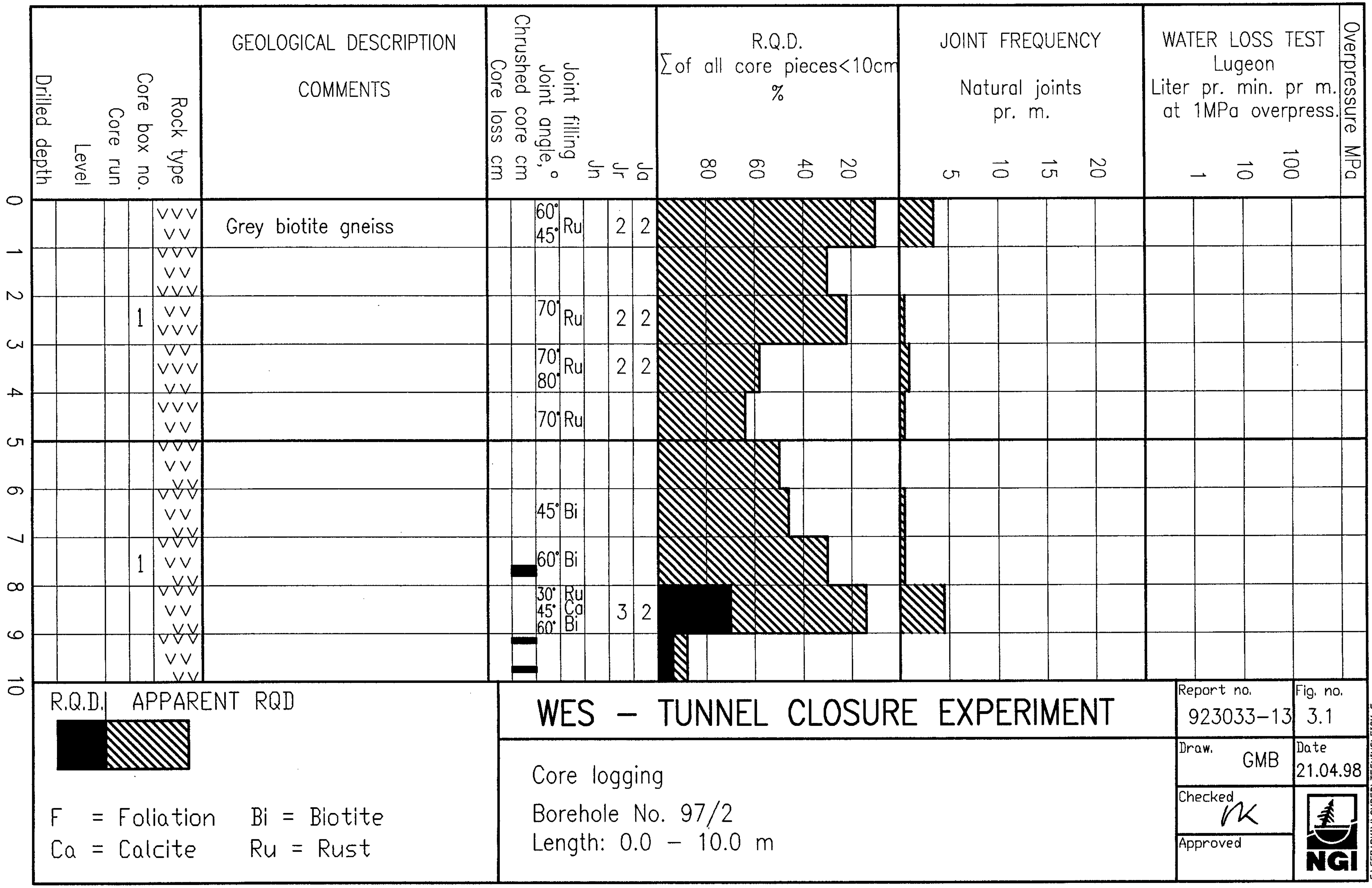
0.0-11.0 m

10.0 m



20.0 m

| | | |
|---|---|---|
| **WES - TUNNEL CLOSURE EXPERIMENT** | Report No. 933033-13 | Figure No. 2.3 |
| Photos of diamond drilled cores<br>Borehole 97/1 | Drawn by PC | Date 97-02-28 |
| | Checked | NGI |
| | Approved | |



Drilled depth
Level
Core run
Core box no.
Rock type
GEOLOGICAL DESCRIPTION
COMMENTS
Grey biotite gneiss
Core loss cm
Chrushed core cm
Joint angle, °
Joint filling
Jn
Jr
Ja
R.Q.D.
∑of all core pieces<10cm
%
80
60
40
20
JOINT FREQUENCY
Natural joints
pr. m.
5
10
15
20
WATER LOSS TEST
Lugeon
Liter pr. min. pr m.
at 1MPa overpress.
1
10
100
Overpressure MPa
0
1
2
3
4
5
6
7
8
9
10
60° 45° Ru 2 2
1
70° Ru 2 2
70° 80° Ru 2 2
70° Ru
45° Bi
1
60° Bi
30° 45° 60° Ru Ca Bi 3 2
R.Q.D. APPARENT RQD
F = Foliation
Ca = Calcite
Bi = Biotite
Ru = Rust
WES – TUNNEL CLOSURE EXPERIMENT
Core logging
Borehole No. 97/2
Length: 0.0 – 10.0 m
Report no.
923033-13
Fig. no.
3.1
Draw.
GMB
Date
21.04.98
Checked
Approved
NGI
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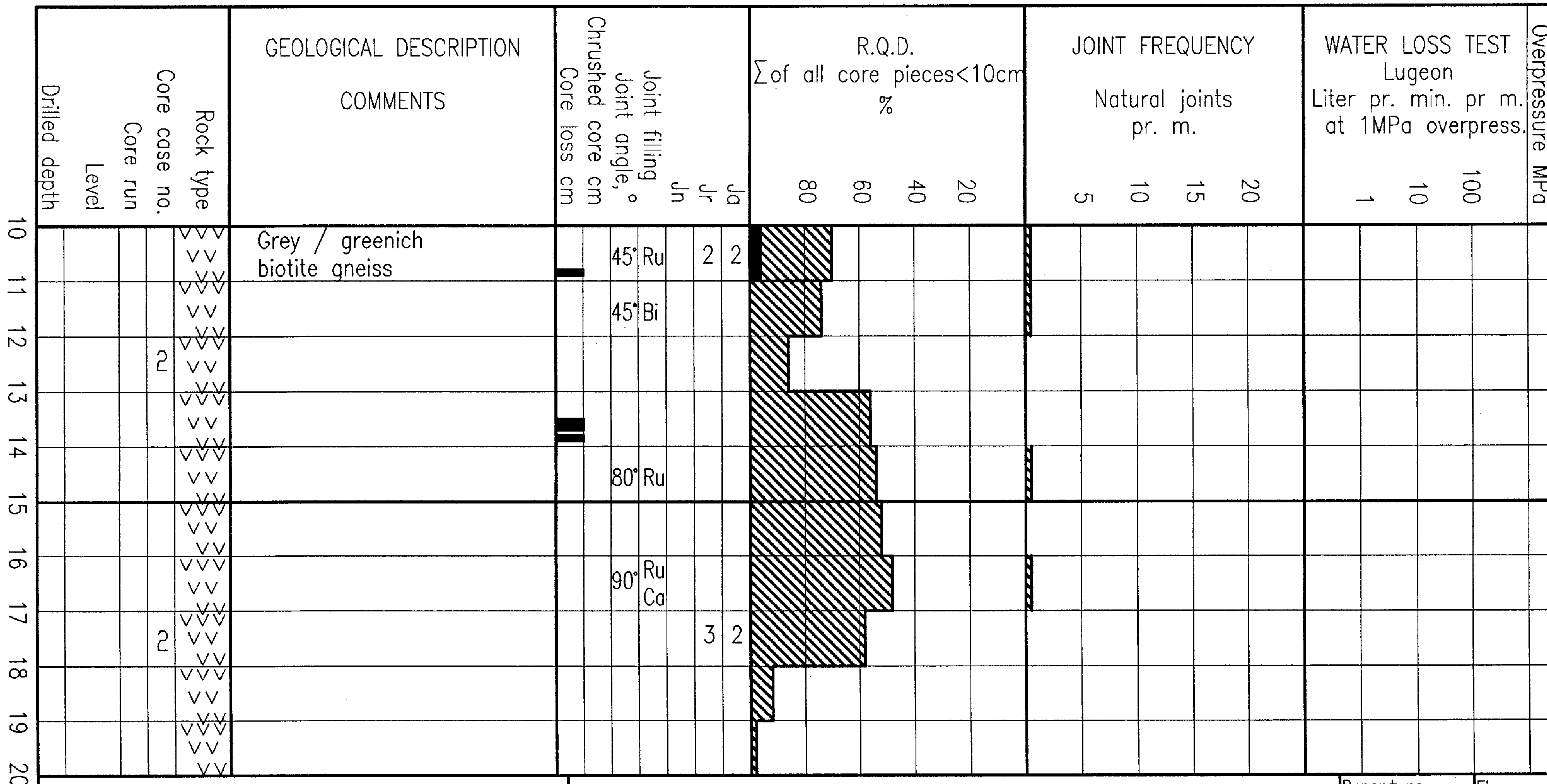


# WES – TUNNEL CLOSURE EXPERIMENT

Core logging

Borehole No. 97/2

Length: 10.0 – 20.0 m

| Report no. | Fig. no. |
|---|---|
| 923033-13 | 3.2 |
| Draw. GMB | Date 21.04.98 |
| Checked | NGI |
| Approved | |

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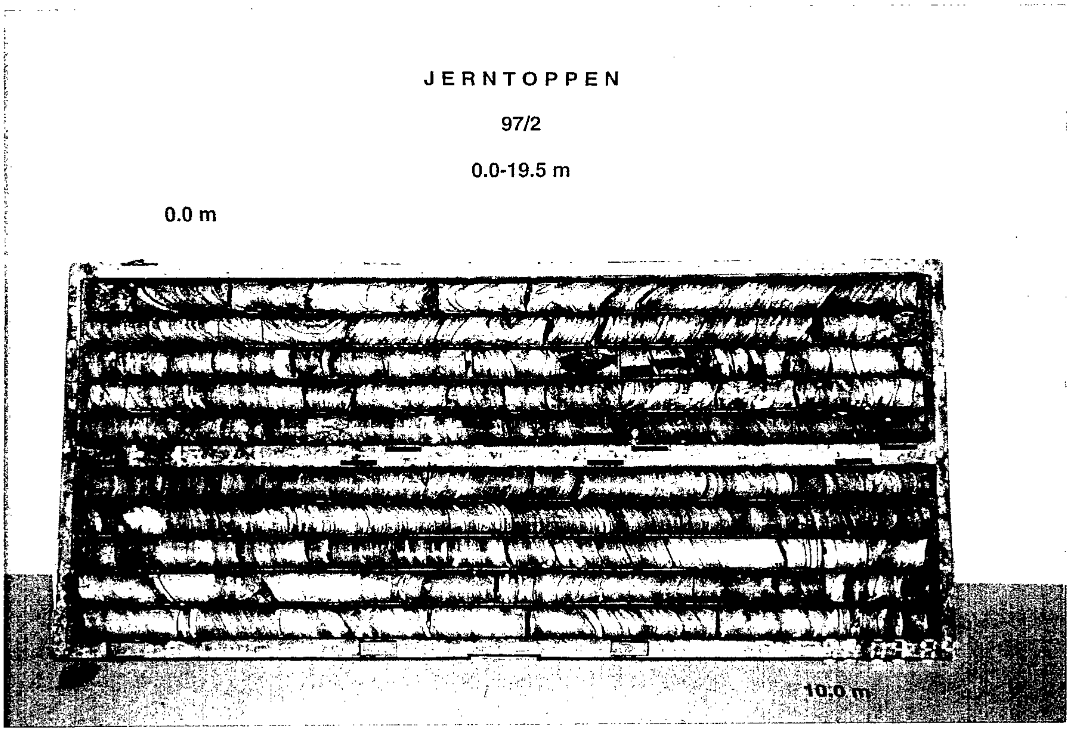
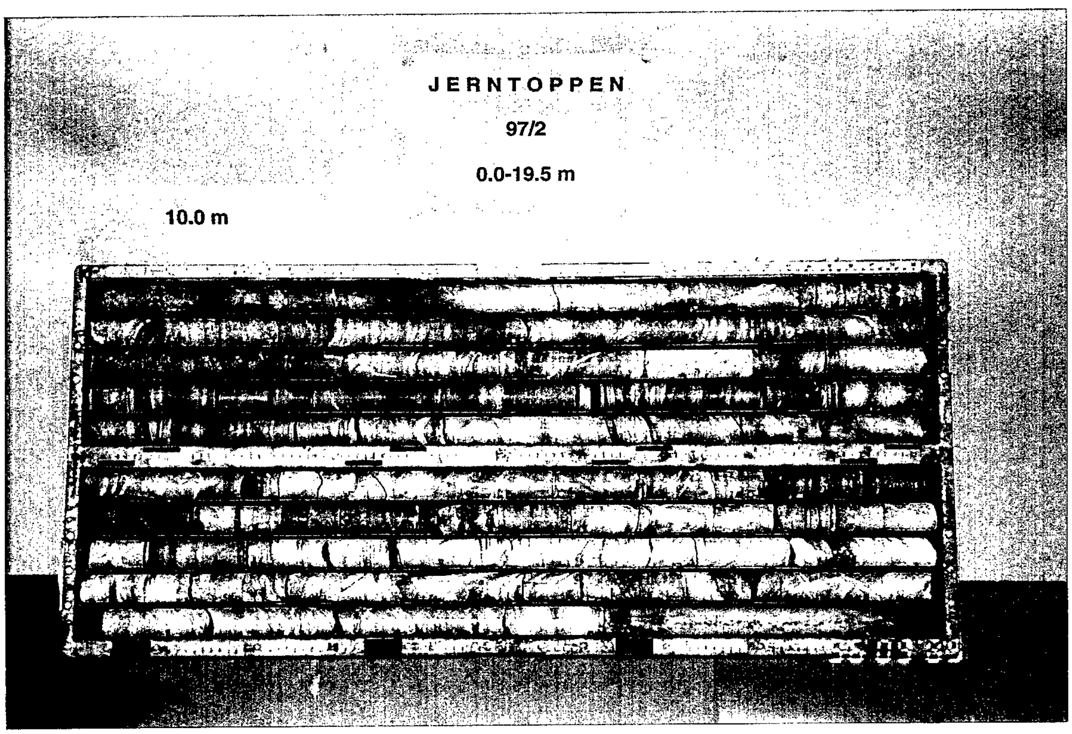
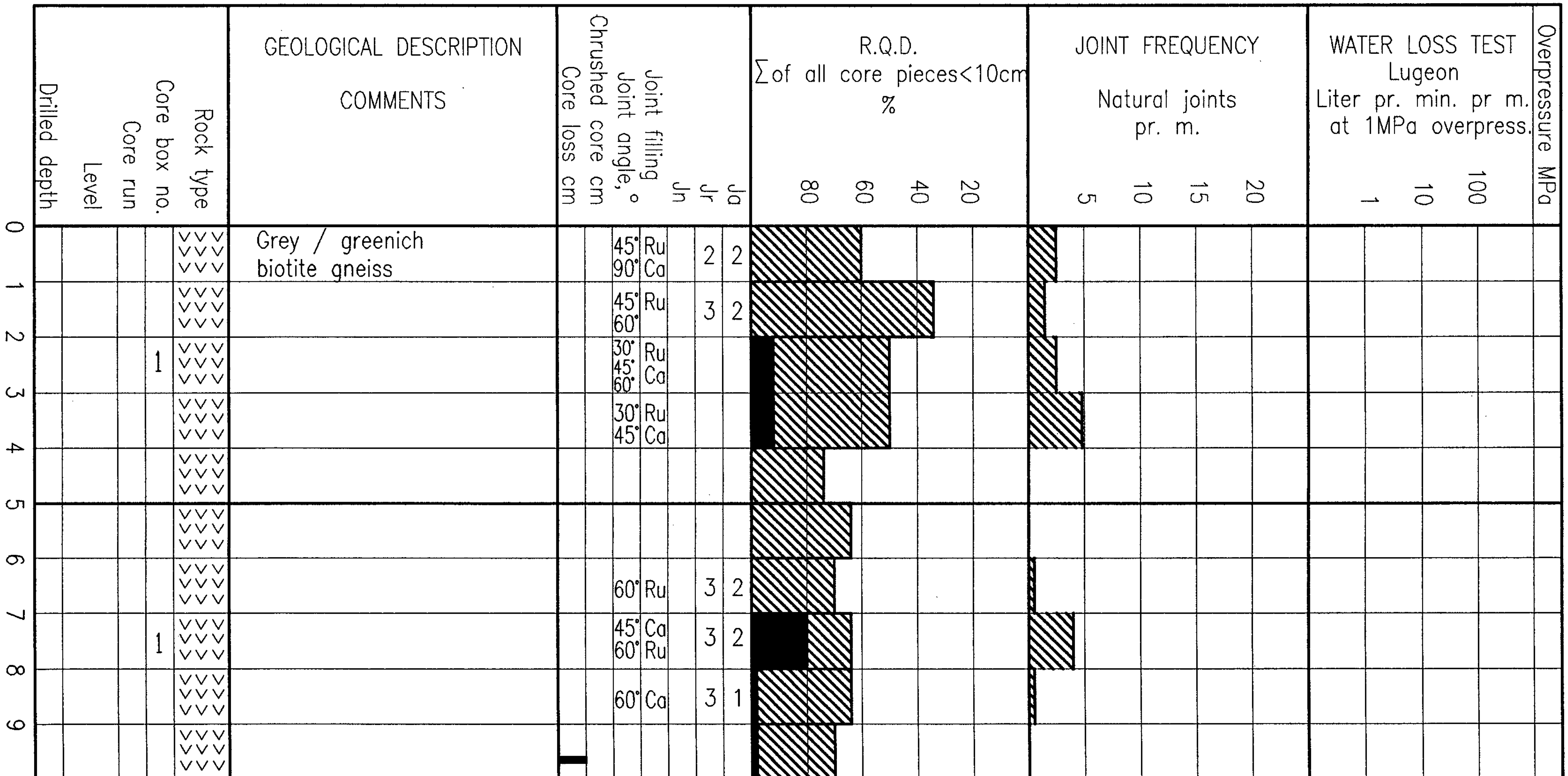



| | | |
|---|---|---|
| **WES - TUNNEL CLOSURE EXPERIMENT** | Report No. 933033-13 | Figure No. 3.3 |
| | Drawn by PC | Date 97-02-28 |
| Photos of diamond drilled cores.<br>Borehole 97/2 | Checked IK<br>Approved | NGI |




R.Q.D.| APPARENT RQD

F = Foliation  Bi = Biotite
Ca = Calcite  Ru = Rust

# WES – TUNNEL CLOSURE EXPERIMENT

Core logging

Borehole No. 97/3
Length: 0.0 – 10.0 m

| | |
|---|---|
| Report no. 923033-13 | Fig. no. 4.1 |
| Draw. GMB | Date 21.04.98 |
| Checked | |
| Approved | NGI |

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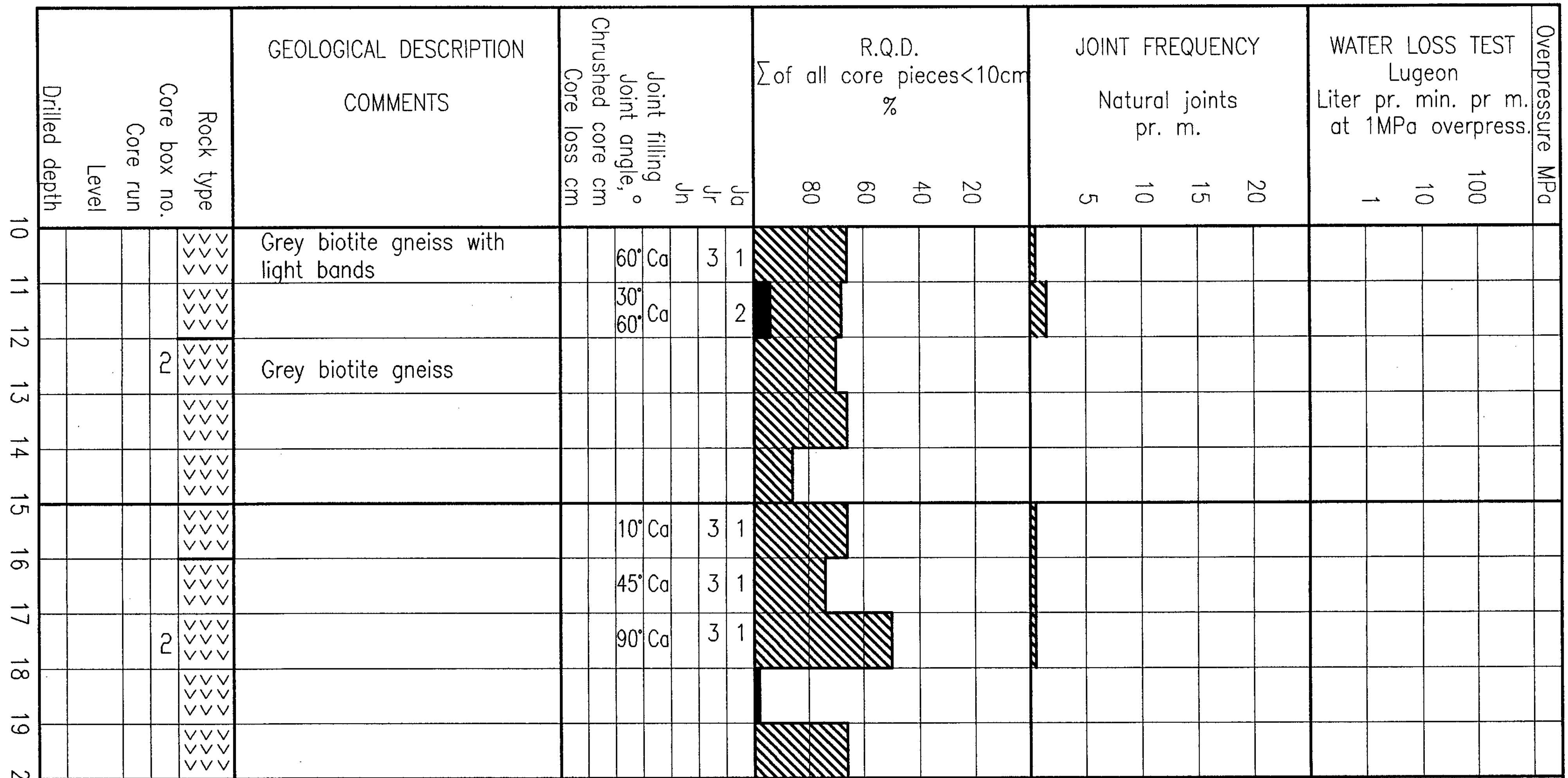


R.Q.D. APPARENT RQD

F = Foliation Bi = Biotite
Ca = Calcite Ru = Rust

# WES – TUNNEL CLOSURE EXPERIMENT

Core logging
Borehole No. 97/3
Length: 10.0 – 20.0 m

| Report no. | Fig. no. |
|---|---|
| 923033-13 | 4.2 |
| Draw. GMB | Date 21.04.98 |
| Checked | NGI |
| Approved | |

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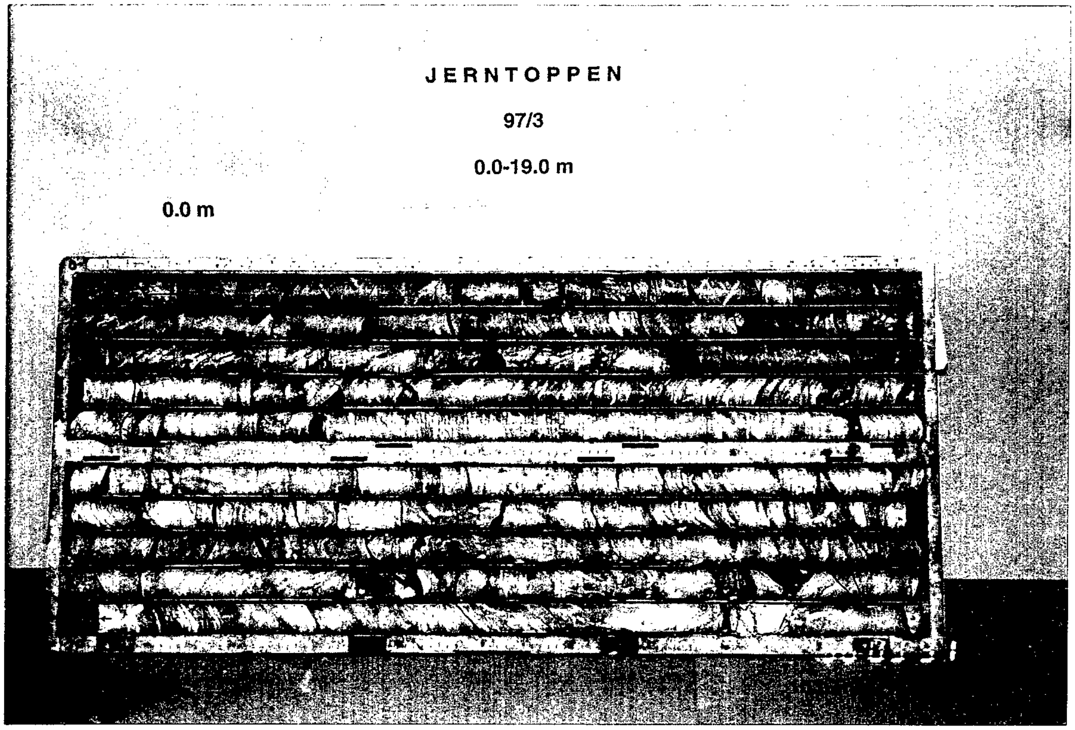
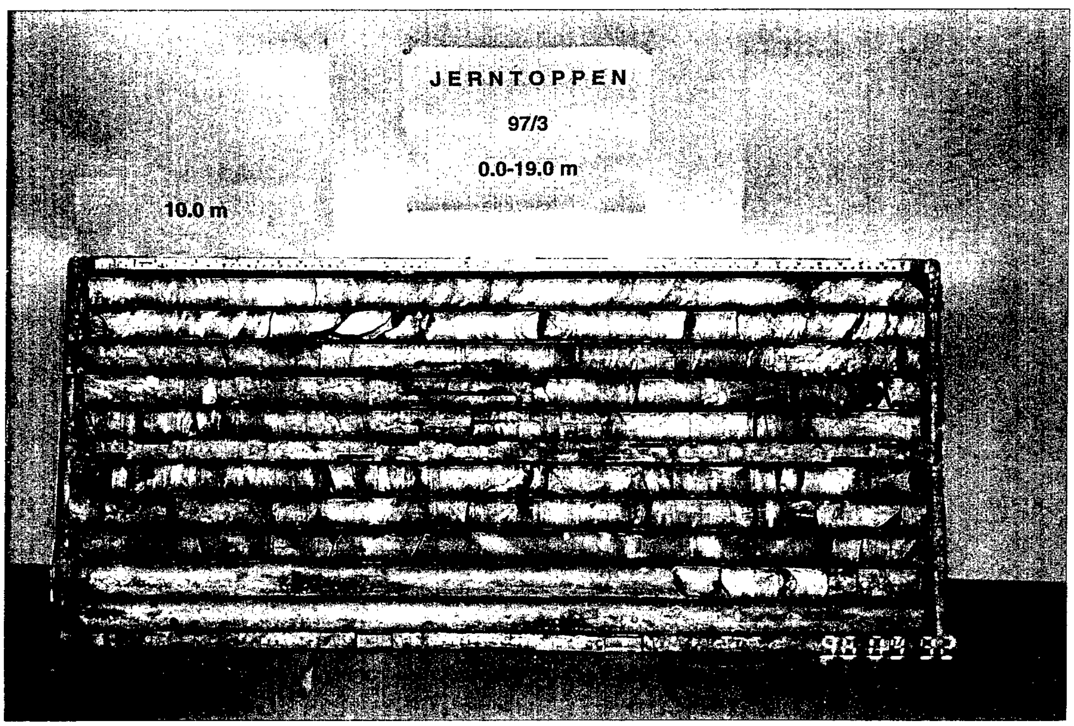
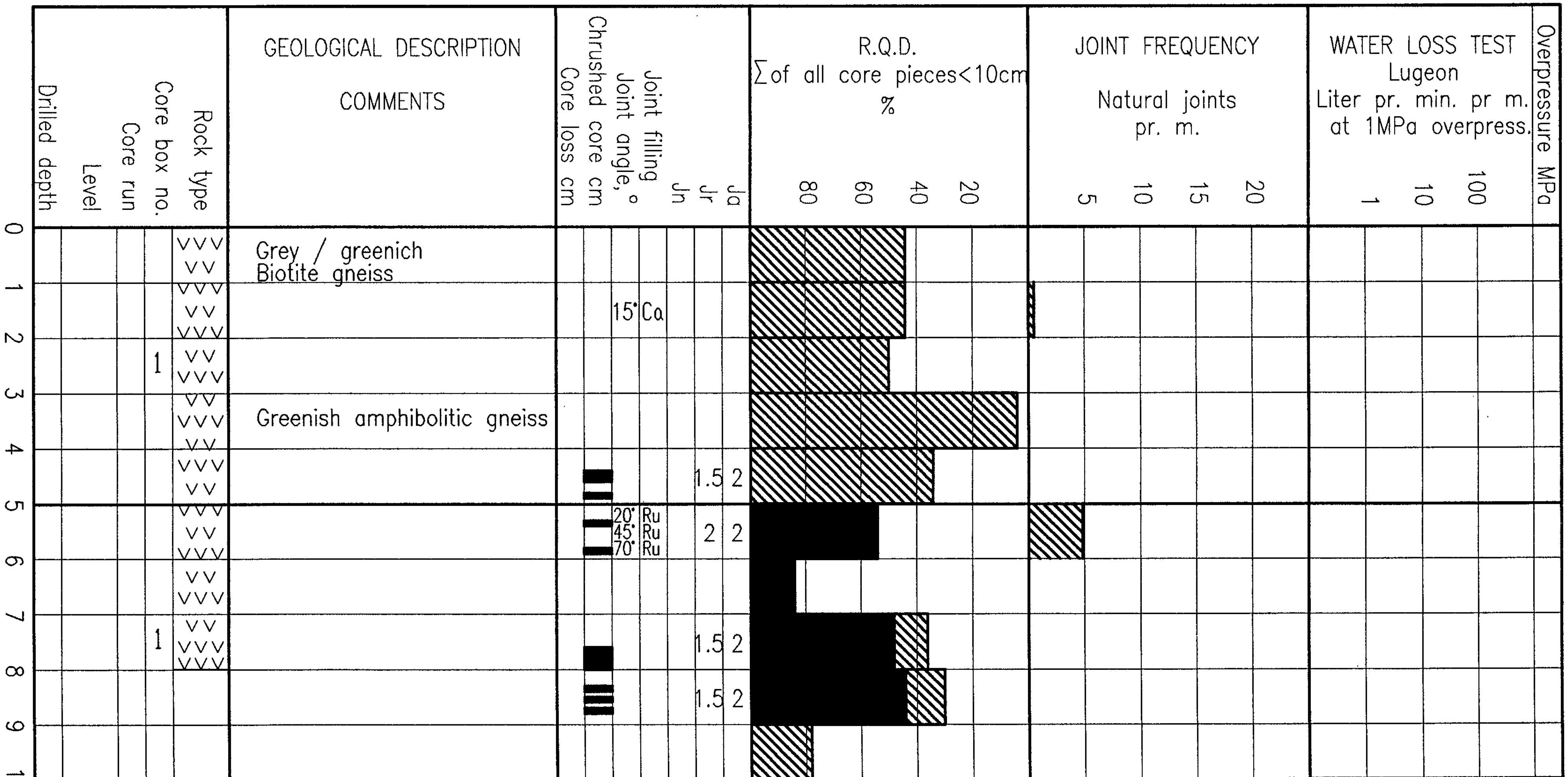



| | | |
|---|---|---|
| **WES - TUNNEL CLOSURE EXPERIMENT** | Report No. 933033-13 | Figure No. 4.3 |
| | Drawn by PC | Date 97-02-28 |
| Photos of diamond drilled cores<br>Borehole 97/3 | Checked<br>Approved | NGI |




# WES – TUNNEL CLOSURE EXPERIMENT

Core logging

Borehole No. 97/5

Length: 0.0 – 10.0 m

| | |
|---|---|
| Report no. 923033-13 | Fig. no. 5.1 |
| Draw. GMB | Date 21.04.98 |
| Checked | NGI |
| Approved | |

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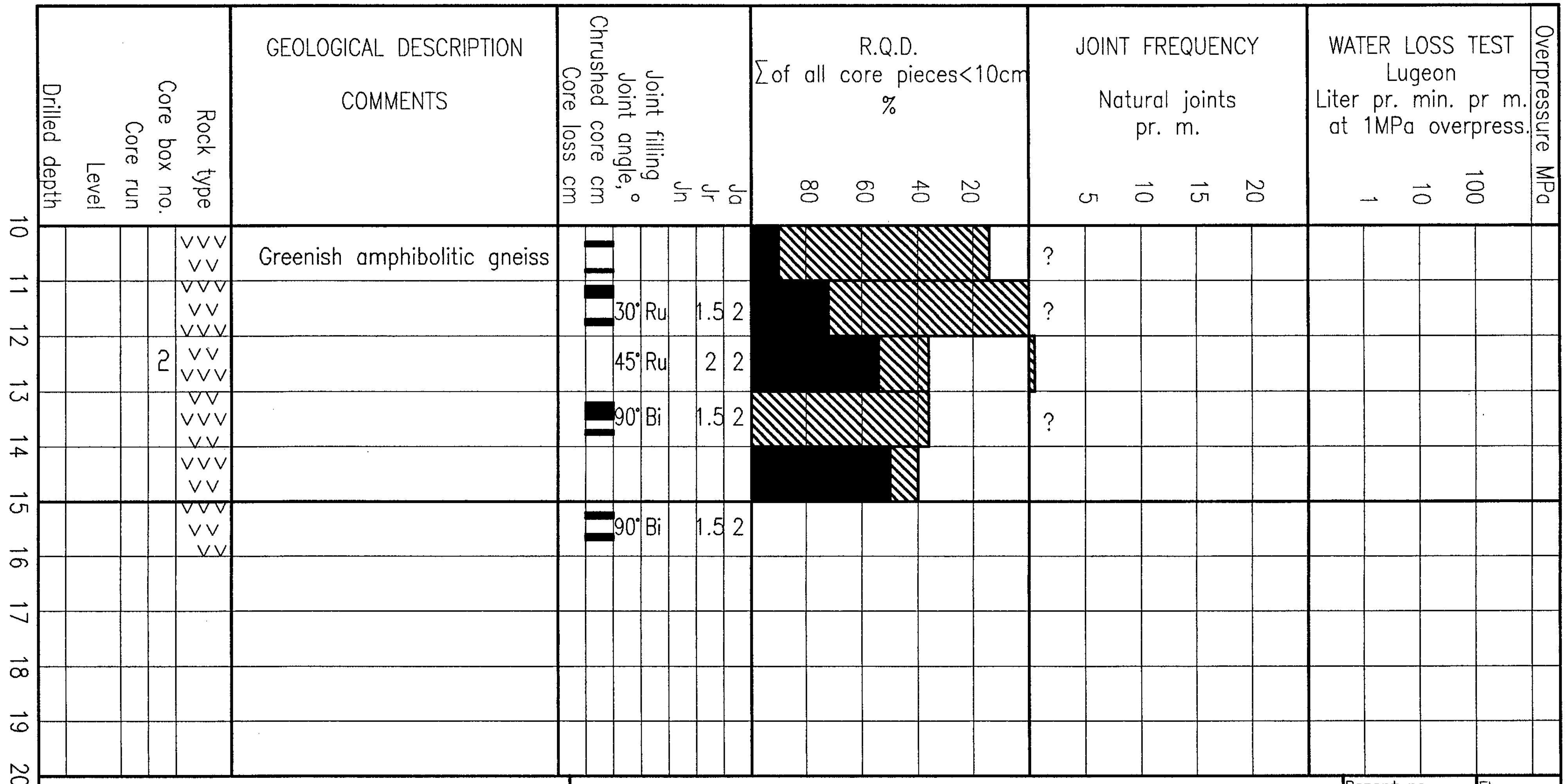


R.Q.D. APPARENT RQD

F = Foliation  Bi = Biotite
Ca = Calcite  Ru = Rust

# WES – TUNNEL CLOSURE EXPERIMENT

Core logging

Borehole No. 97/5
Length: 10.0 – 15.5 m

| | |
|---|---|
| Report no. 923033–13 | Fig. no. 5.2 |
| Draw. GMB | Date 21.04.98 |
| Checked | NGI |
| Approved | |

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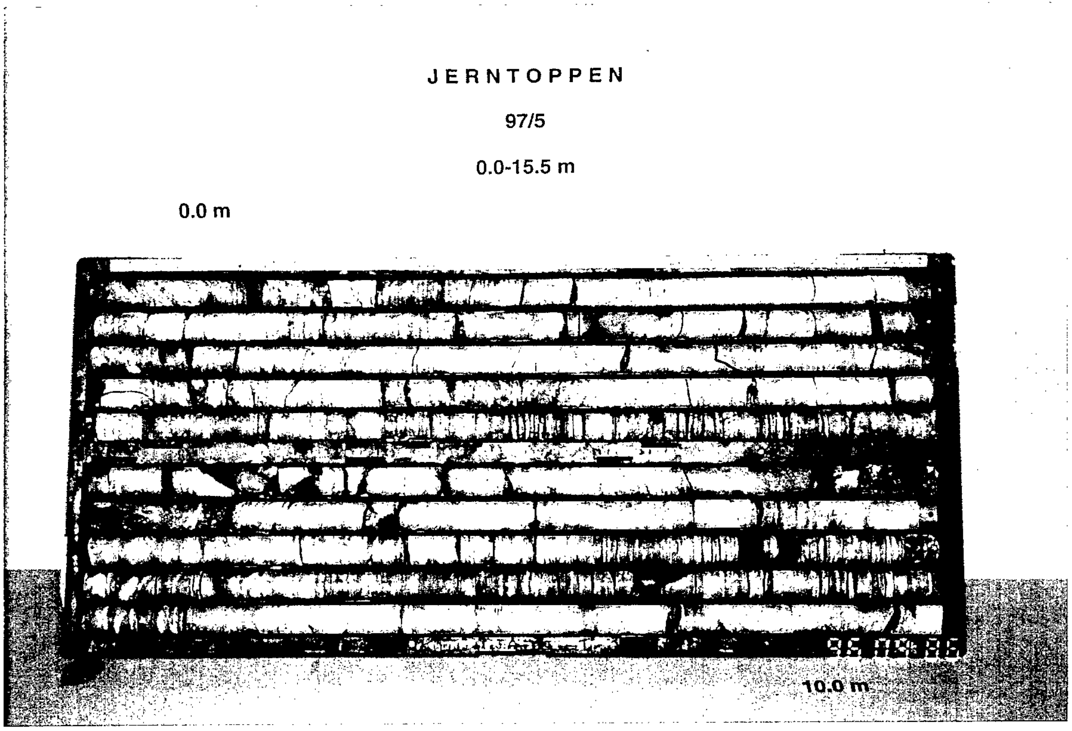
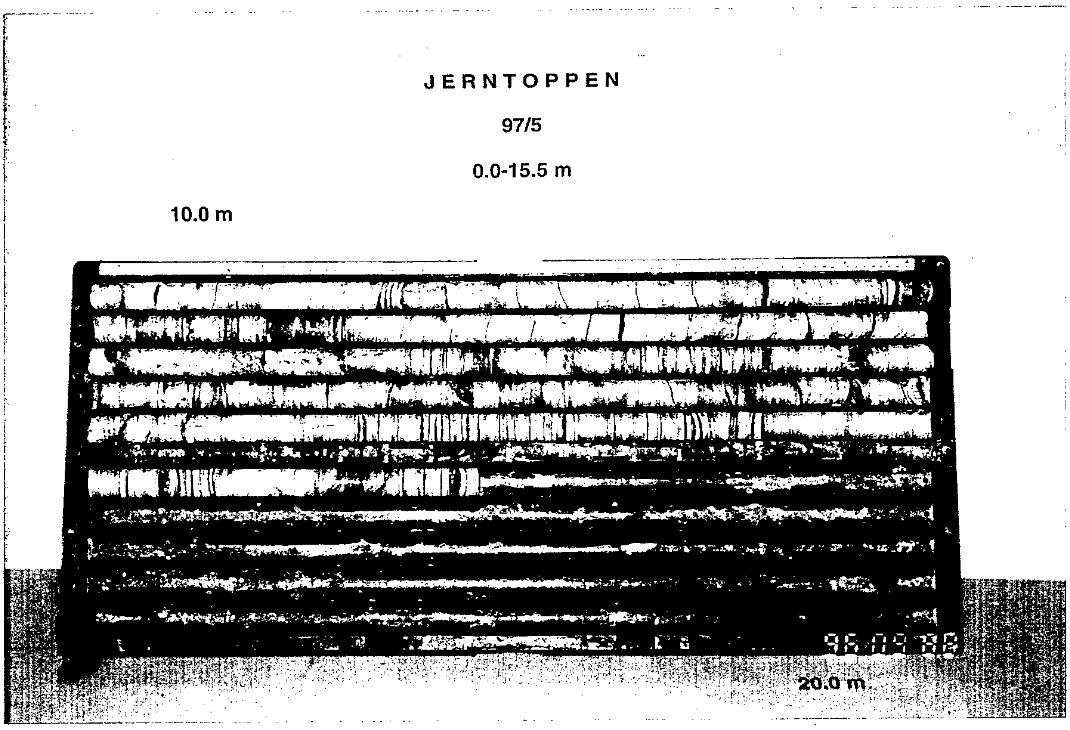
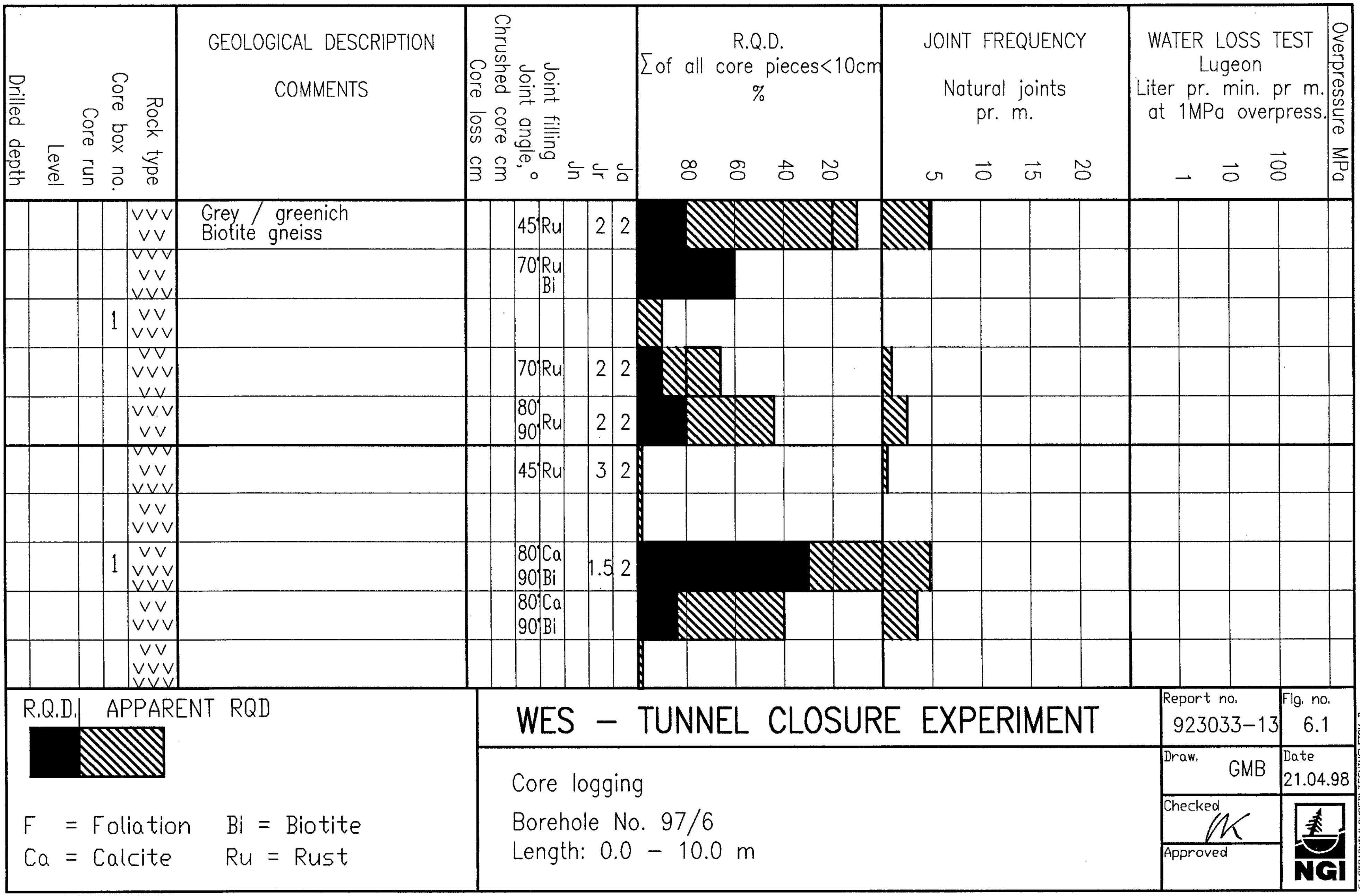
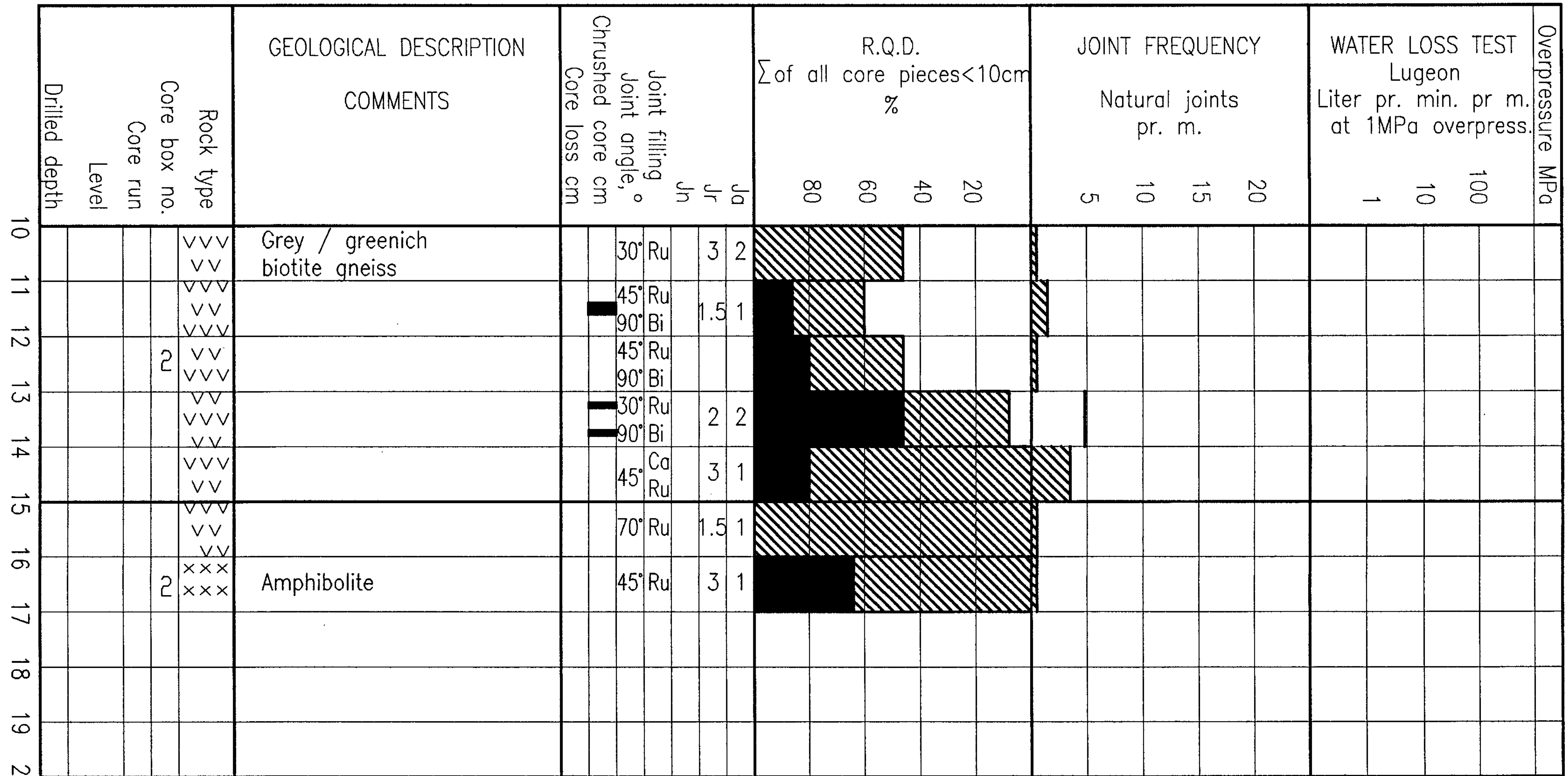



| WES - TUNNEL CLOSURE EXPERIMENT | Report No. 933033-13 | Figure No. 5.3 |
|---|---|---|
| Photos of diamond drilled cores<br>Borehole 97/5 | Drawn by PC | Date 97-02-28 |
| | Checked VK | NGI |
| | Approved | |


GEOLOGICAL DESCRIPTION
COMMENTS
Drilled depth
Level
Core run
Core box no.
Rock type
Grey / greenich Biotite gneiss
Chrushed core cm
Core loss cm
Joint angle, °
Joint filling
Jn
Jr
Ja
R.Q.D.
∑of all core pieces<10cm
%
80
60
40
20
JOINT FREQUENCY
Natural joints pr. m.
5
10
15
20
WATER LOSS TEST
Lugeon
Liter pr. min. pr m. at 1MPa overpress.
1
10
100
Overpressure MPa
45° Ru 2 2
70° Ru Bi
1
70° Ru 2 2
80° 90° Ru 2 2
45° Ru 3 2
1
80° Ca 90° Bi 1.5 2
80° Ca 90° Bi
0
1
2
3
4
5
6
7
8
9
10
R.Q.D. APPARENT RQD
F = Foliation
Bi = Biotite
Ca = Calcite
Ru = Rust
WES – TUNNEL CLOSURE EXPERIMENT
Core logging
Borehole No. 97/6
Length: 0.0 – 10.0 m
Report no. 923033-13
Fig. no. 6.1
Draw. GMB
Date 21.04.98
Checked
Approved
NGI
G:\GEOARKIV\SKRED\TEGNING\FISK-B




R.Q.D. | APPARENT RQD

F = Foliation    Bi = Biotite
Ca = Calcite    Ru = Rust

# WES – TUNNEL CLOSURE EXPERIMENT

Core logging

Borehole No. 97/6
Length: 10.0 – 17.0 m

| | |
|---|---|
| Report no. 923033-13 | Fig. no. 6.2 |
| Draw. GMB | Date 21.04.98 |
| Checked | |
| Approved | NGI |

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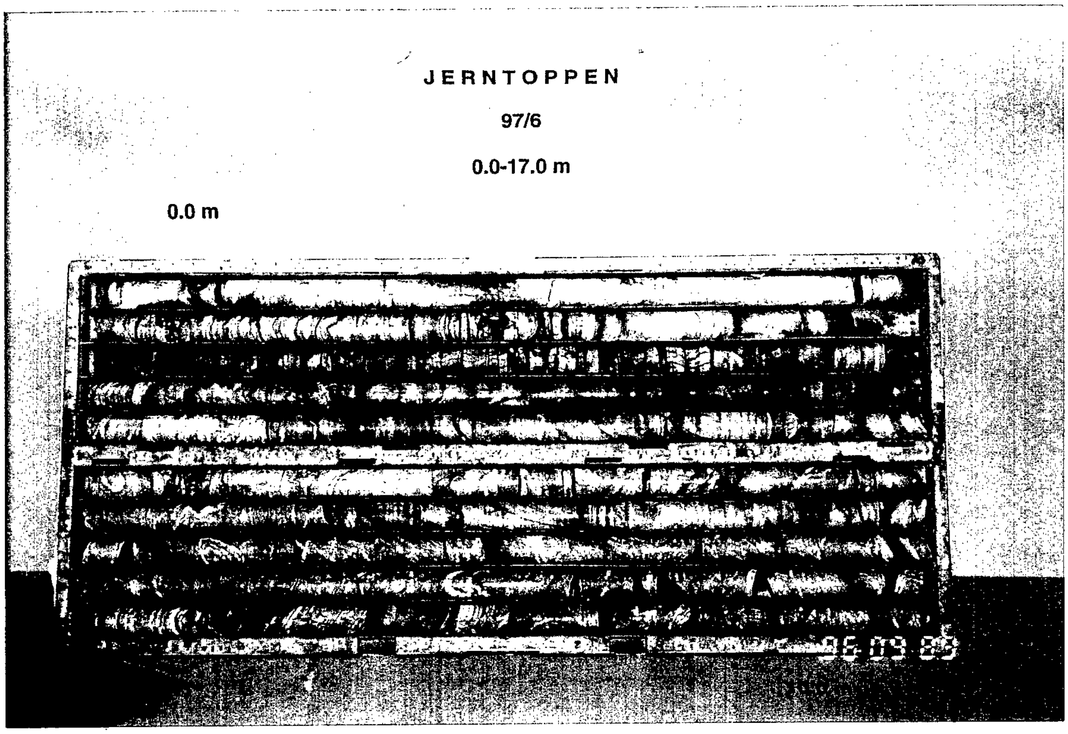
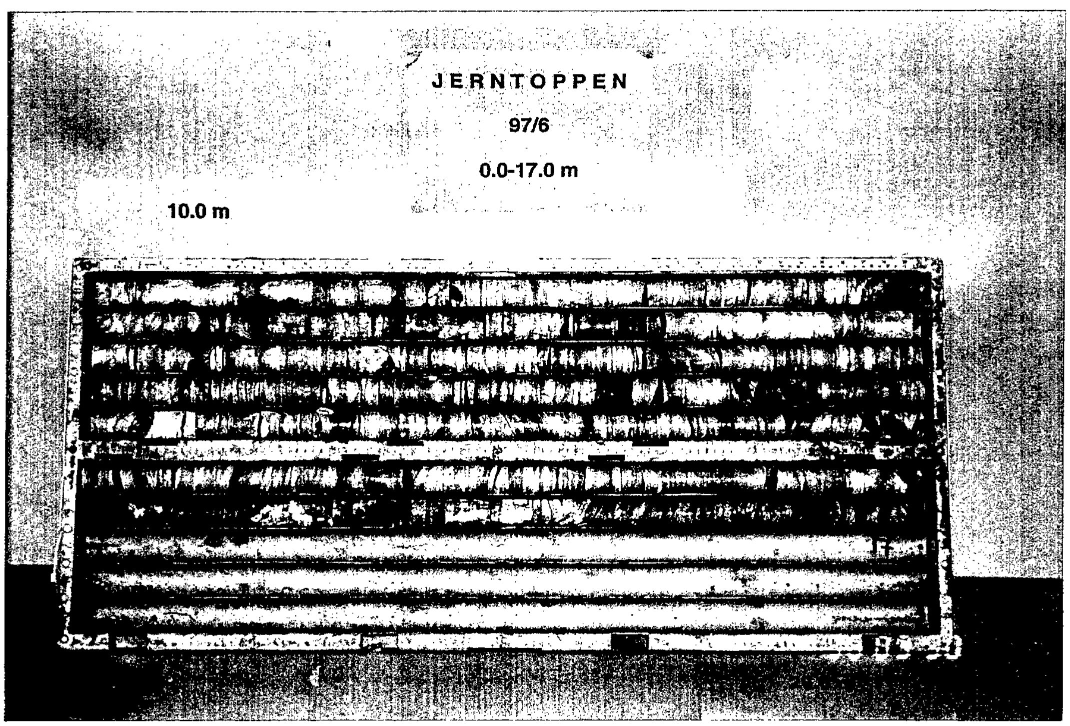
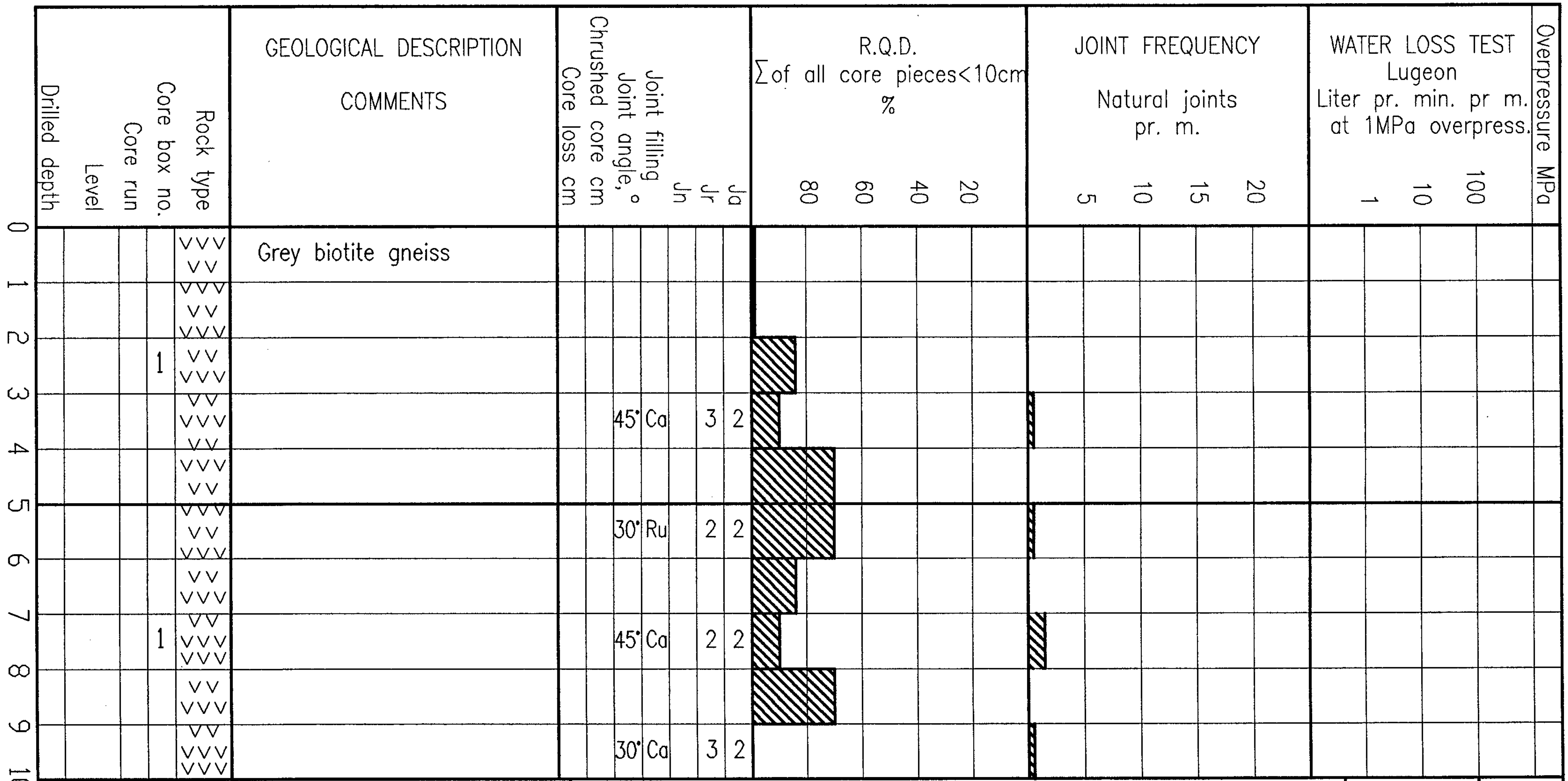



| **WES - TUNNEL CLOSURE EXPERIMENT** | Report No. 933033-13 | Figure No. 6.3 |
|---|---|---|
| | Drawn by PC | Date 97-02-28 |
| Photos of diamond drilled cores<br>Borehole 97/6 | Checked VK<br>Approved | NGI |




R.Q.D.| APPARENT RQD

F = Foliation Bi = Biotite
Ca = Calcite Ru = Rust

**WES – TUNNEL CLOSURE EXPERIMENT**

Core logging
Borehole No. 97/7
Length: 0.0 – 10.0 m

| | |
|---|---|
| Report no. 923033–13 | Fig. no. 7.1 |
| Draw. GMB | Date 21.04.98 |
| Checked | NGI |
| Approved | |

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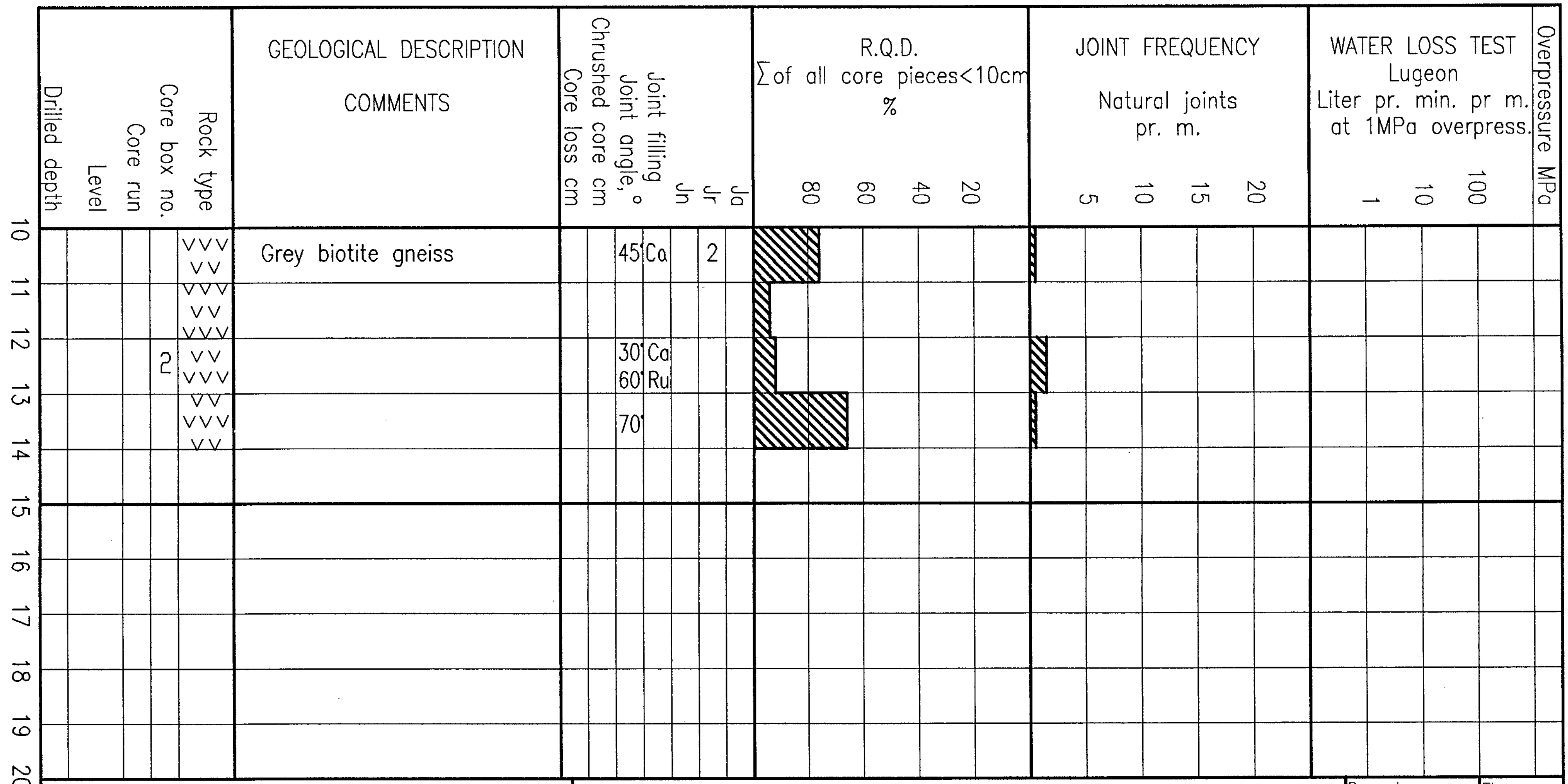


R.Q.D. | APPARENT RQD

F = Foliation Bi = Biotite
Ca = Calcite Ru = Rust

# WES– TUNNEL CLOSURE EXPERIMENT

Core logging

Borehole No. 97/7
Length: 10.0 – 14.5 m

| | |
|---|---|
| Report no. 923033–13 | Fig. no. 7.2 |
| Draw. GMB | Date 21.04.98 |
| Checked | NGI |
| Approved | |

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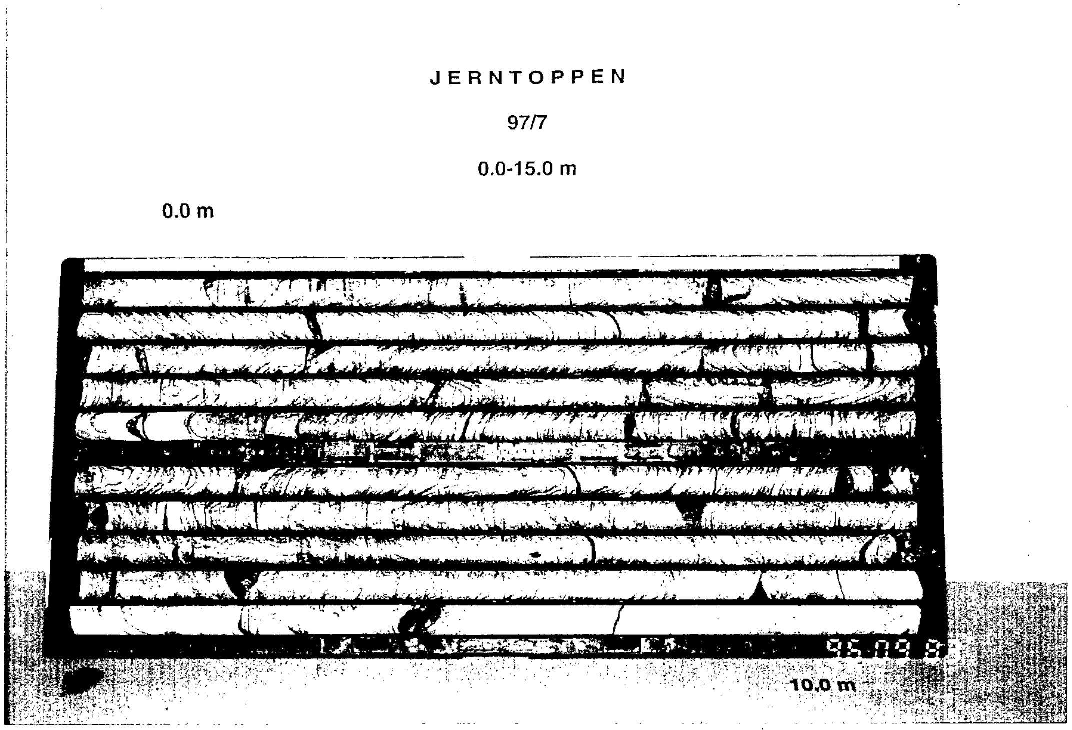
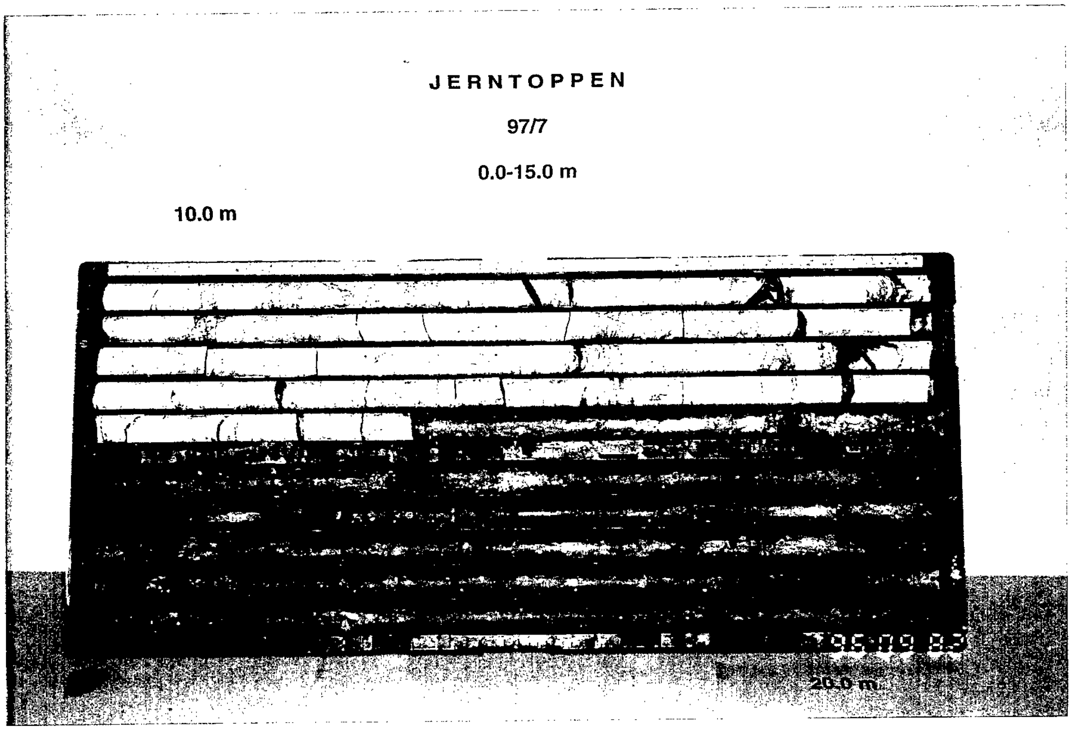



| | | |
|---|---|---|
| **WES - TUNNEL CLOSURE EXPERIMENT** | Report No. 933033-13 | Figure No. 7.3 |
| Photos of diamond drilled cores<br>Borehole 97/7 | Drawn by PC | Date 97-02-28 |
| | Checked<br>Approved | NGI |

# WES – TUNNEL CLOSURE EXPERIMENT

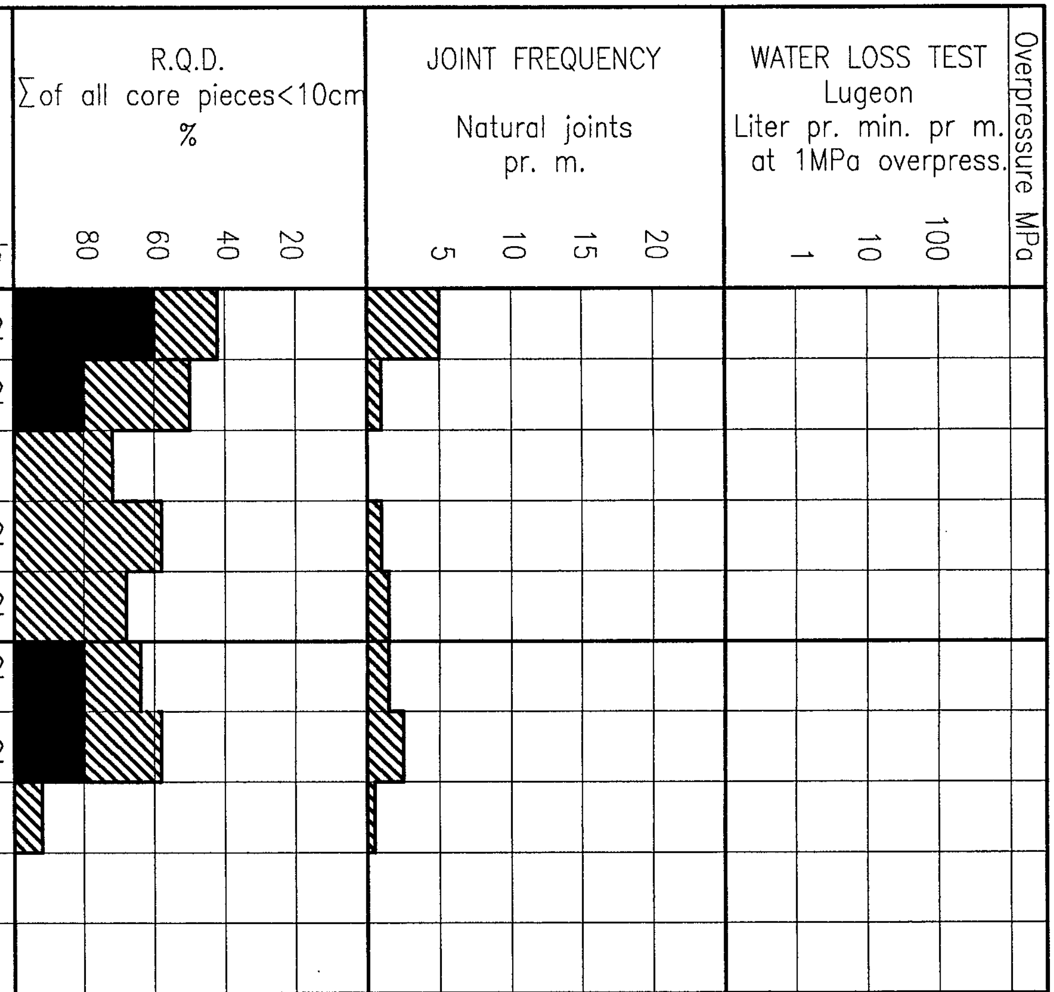
Core logging

Borehole No. 97/8

Length: 0.0 – 8.2 m

| Drilled depth (m) | Core box no. | GEOLOGICAL DESCRIPTION / COMMENTS | Joint angle, ° | Joint filling | Jn | Jr | Ja |
|---|---|---|---|---|---|---|---|
| 0–1 | | Grey biotite gneiss | 60<br>45 | Ru | | 1,5 | 2 |
| 1–2 | | Grey/greenich biotite gneiss | 30 | Ru | | 2 | 2 |
| 2–3 | 1 | —— " —— | | | | | |
| 3–4 | | Grey biotite gneiss | 45 | Ru | | 2 | 2 |
| 4–5 | | Grey/greenich biotite gneiss | 20 | Ru | | 3 | 2 |
| 5–6 | | —— " —— | 20 | Ru | | 3 | 2 |
| 6–7 | | —— " —— | 30<br>45 | Ca<br>Bi | | 2 | 2 |
| 7–8 | 1 | —— " —— | | | | | |
| 8–9 | | | | | | | |
| 9–10 | | | | | | | |

Rock type, Core run, Level, Chrushed core cm, Core loss cm.




R.Q.D. | APPARENT RQD

F = Foliation  Bi = Biotite

Ca = Calcite  Ru = Rust

Report no. 923033-13 | Fig. no. 8.1

Draw. GMB | Date 21.04.98

Checked | Approved

NGI

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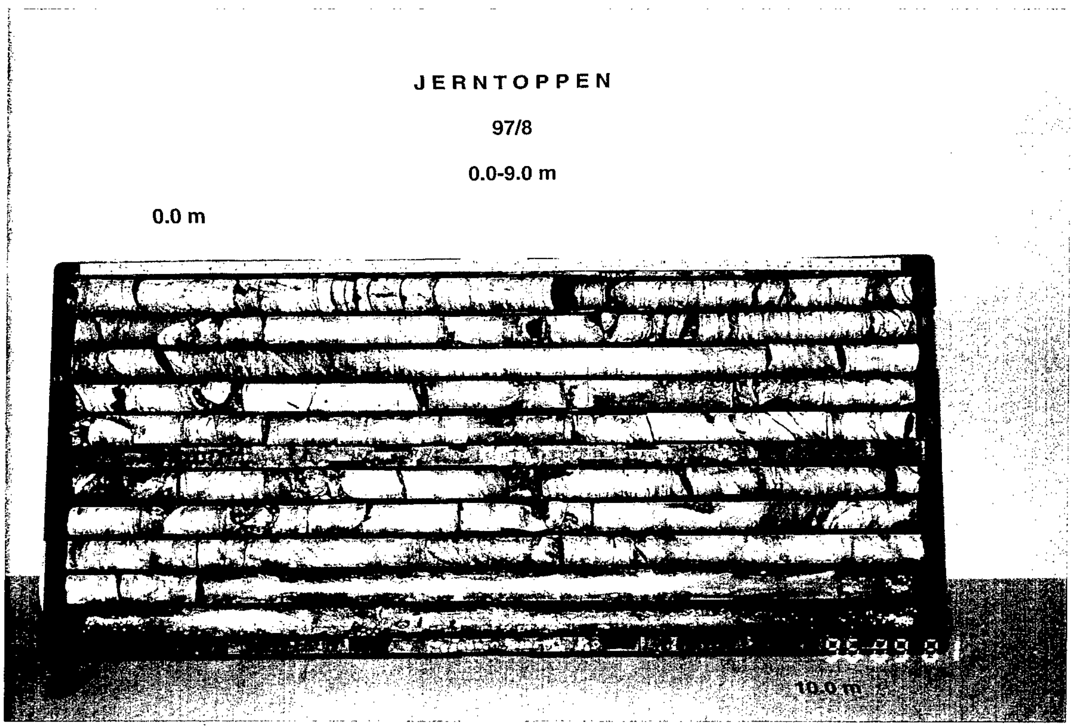



| | | |
|---|---|---|
| **WES - TUNNEL CLOSURE EXPERIMENT** | Report No. 933033-13 | Figure No. 8.2 |
| Photo of diamond drilled cores<br>Borehole 97/8 | Drawn by PC | Date 97-02-28 |
| | Checked VK | NGI |
| | Approved | |

| 1. Rock Quality Designation | | RQD |
|---|---|---|
| A | Very poor | 0 - 25 |
| B | Poor | 25 - 50 |
| C | Fair | 50 - 75 |
| D | Good | 75 - 90 |
| E | Excellent | 90 - 100 |

Note: i) Where RQD is reported or measured as ≤ 10 (including 0), a nominal value of 10 is used to evaluate Q.
ii) RQD intervals of 5, *i.e.*, 100, 95, 90, *etc.*, are sufficiently accurate.

| 2. Joint Set Number | | $J_n$ |
|---|---|---|
| A | Massive, no or few joints | 0.5 - 1.0 |
| B | One joint set | 2 |
| C | One joint set plus random joints | 3 |
| D | Two joint sets | 4 |
| E | Two joint sets plus random joints | 6 |
| F | Three joint sets | 9 |
| G | Three joint sets plus random joints | 12 |
| H | Four or more joint sets, random, heavily jointed, "sugar cube", *etc.* | 15 |
| J | Crushed rock, earthlike | 20 |

Note: i) For intersections, use $(3.0 \times J_n)$
ii) For portals, use $2.0 \times J_n$)

| 3. Joint Roughness Number | | $J_r$ |
|---|---|---|
| ***a) Rock-wall contact, and b) rock-wall contact before 10 cm shear*** | | |
| A | Discontinuous joints | 4 |
| B | Rough or irregular, undulating | 3 |
| C | Smooth, undulating | 2 |
| D | Slickensided, undulating | 1.5 |
| E | Rough or irregular, planar | 1.5 |
| F | Smooth, planar | 1.0 |
| G | Slickensided, planar | 0.5 |

Note: i) Descriptions refer to small scale features and intermediate scale features, in that order.

| ***c) No rock-wall contact when sheared*** | | |
|---|---|---|
| H | Zone containing clay minerals thick enough to prevent rock-wall contact | 1.0 |
| J | Sandy, gravelly or crushed zone thick enough to prevent rock-wall contact | 1.0 |

Note: i) Add 1.0 if the mean spacing of the relevant joint set is greater than 3m.
ii) $J_r$ = 0.5 can be used for planar slickensided joints having lineations, provided the lineations are oriented for minimum strength.

| 4. Joint Alteration Number | | $\phi_r$ approx. | $J_a$ |
|---|---|---|---|
| ***a) Rock-wall contact (no mineral fillings, only coatings)*** | | | |
| A | Tightly healed, hard, non-softening, impermeable filling, *i.e.*, quartz or epidote | | 0.75 |
| B | Unaltered joint walls, surface staining only | 25-35° | 1.0 |
| C | Slightly altered joint walls. Non-softening mineral coatings, sandy particles, clay-free disintegrated rock, *etc.* | 25-30° | 2.0 |
| D | Silty- or sandy-clay coatings, small clay fraction (non-softening) | 20-25° | 3.0 |
| E | Softening or low friction clay mineral coatings, *i.e.*, kaolinite or mica. Also chlorite, talc, gypsum, graphite, *etc.*, and small quantities of swelling clays. | 8-16° | 4.0 |
| ***b) Rock-wall contact before 10 cm shear (thin mineral fillings)*** | | | |
| F | Sandy particles, clay-free disintegrated rock, *etc.* | 25-30° | 4.0 |
| G | Strongly over-consolidated non-softening clay mineral fillings (continuous, but <5mm thickness) | 16-24° | 6.0 |
| H | Medium or low over-consolidation, softening, clay mineral fillings (continuous, but <5mm thickness) | 12-16° | 8.0 |
| J | Swelling-clay fillings, *i.e.*, montmorillonite (continuous, but <5mm thickness). Value of $J_a$ depends on percent of swelling clay-size particles, and access to water, *etc.* | 6-12° | 8-12 |
| ***c) No rock-wall contact when sheared (thick mineral fillings)*** | | | |
| KLM | Zones or bands of disintegrated or crushed rock and clay (see G, H, J for description of clay condition) | 6-24° | 6, 8, or 8-12 |
| N | Zones or bands of silty- or sandy-clay, small clay fraction (non-softening) | - | 5.0 |
| OPR | Thick, continuous zones or bands of clay (see G, H, J for description of clay condition) | 6-24° | 10, 13, or 13-20 |

| 5. Joint Water Reduction Factor | | approx water pres. (kg/cm²) | $J_w$ |
|---|---|---|---|
| A | Dry excavations or minor inflow, *i.e.*, <5 l/min locally | <1 | 1.0 |
| B | Medium inflow or pressure, occasional outwash of joint fillings | 1-2.5 | 0.66 |
| C | Large inflow or high pressure in competent rock with unfilled joints | 2.5-10 | 0.5 |
| D | Large inflow or high pressure, considerable outwash of joint fillings | 2.5-10 | 0.33 |
| E | Exceptionally high inflow or water pressure at blasting, decaying with time | >10 | 0.2-0.1 |
| F | Exceptionally high inflow or water pressure continuing without noticeable decay | >10 | 0.1-0.05 |

Note: i) Factors C to F are crude estimates. Increase $J_w$ if drainage measures are installed.
ii) Special problems caused by ice formation are not considered.

| 6. Stress Reduction Factor | | SRF |
|---|---|---|
| ***a) Weakness zones intersecting excavation, which may cause loosening of rock mass when tunnel is excavated*** | | |
| A | Multiple occurrences of weakness zones containing ***clay*** or chemically disintegrated rock, very loose surrounding rock (any depth) | 10 |
| B | Single weakness zones containing ***clay*** or chemically disintegrated rock (depth of excavation ≤ 50m) | 5 |
| C | Single weakness zones containing ***clay*** or chemically disintegrated rock (depth of excavation > 50m) | 2.5 |
| D | Multiple shear zones in competent rock (***clay-free***), loose surrounding rock (any depth) | 7.5 |
| E | Single shear zones in competent rock (***clay-free***) (depth of excavation ≤ 50m) | 5.0 |
| F | Single shear zones in competent rock (***clay-free***) (depth of excavation > 50m) | 2.5 |
| G | Loose, open joints, heavily jointed or "sugar cube", *etc.* (any depth) | 5.0 |

Note: i) Reduce these values of SRF by 25-50% if the relevant shear zones only influence but do not intersect the excavation.

| ***b) Competent rock, rock stress problems*** | | $\sigma_c/\sigma_1$ | $\sigma_\theta/\sigma_c$ | SRF |
|---|---|---|---|---|
| H | Low stress, near surface, open joints | >200 | <0.01 | 2.5 |
| J | Medium stress, favourable stress condition | 200-10 | 0.01-0.3 | 1 |
| K | High stress, very tight structure. Usually favourable to stability, may be unfavourable for wall stability. | 10-5 | 0.3-0.4 | 0.5-2 |
| L | Moderate slabbing after >1 hour in ***massive*** rock | 5-3 | 0.5-0.65 | 5-50 |
| M | Slabbing and rock burst after a few minutes in ***massive*** rock | 3-2 | 0.65-1 | 50-200 |
| N | Heavy rock burst (strain-burst) and immediate dynamic deformations in ***massive*** rock | <2 | >1 | 200-400 |

Note: ii) For strongly anisotropic virgin stress field (if measured): when $5 \leq \sigma_1/\sigma_3 \leq 10$, reduce $\sigma_c$ to $0.75\sigma_c$. When $\sigma_1/\sigma_3 > 10$, reduce $\sigma_c$ to $0.5\sigma_c$, where $\sigma_c$ = unconfined compression strength, $\sigma_1$ and $\sigma_3$ are the major and minor principal stresses, and $\sigma_\theta$ = maximum tangential stress (estimated from elastic theory).
iii) Few case records available where depth of crown below surface is less than span width. Suggest SRF increase from 2.5 to 5 for such cases (see H).

| ***c) Squeezing rock: plastic flow of incompetent rock under the influence of high rock pressure*** | | $\sigma_\theta/\sigma_c$ | SRF |
|---|---|---|---|
| O | Mild squeezing rock pressure | 1-5 | 5-10 |
| P | Heavy squeezing rock pressure | >5 | 10-20 |

Note: iv) Cases of squeezing rock may occur for depth $H > 350\,Q^{1/3}$ (Singh *et al.*, 1992). Rock mass compression strength can be estimated from $q \approx 0.7\,\gamma\,Q^{1/3}$(MPa) where $\gamma$ = rock density in kN/m³ (Singh, 1993).

| ***d) Swelling rock: chemical swelling activity depending on presence of water*** | | SRF |
|---|---|---|
| R | Mild swelling rock pressure | 5-10 |
| S | Heavy swelling rock pressure | 10-15 |

Note: $J_r$ and $J_a$ classification is applied to the joint set or discontinuity that is least favourable for stability both from the point of view of orientation and shear resistance, $\tau$ (where $\tau \approx \sigma_n \tan^{-1}(J_r/J_a)$). Choose the most likely feature to allow failure to initiate.

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

# WES - TUNNEL CLOSURE EXPERIMENT

Report No. 933033-13

Figure No. 9

Drawn by VK

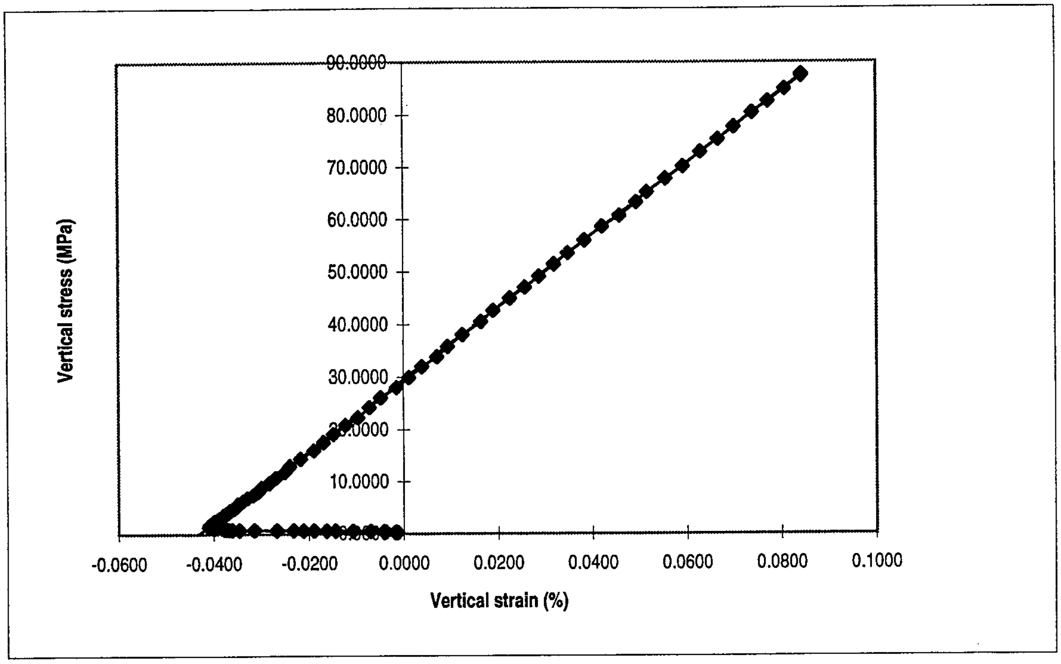
Date 97-04-30

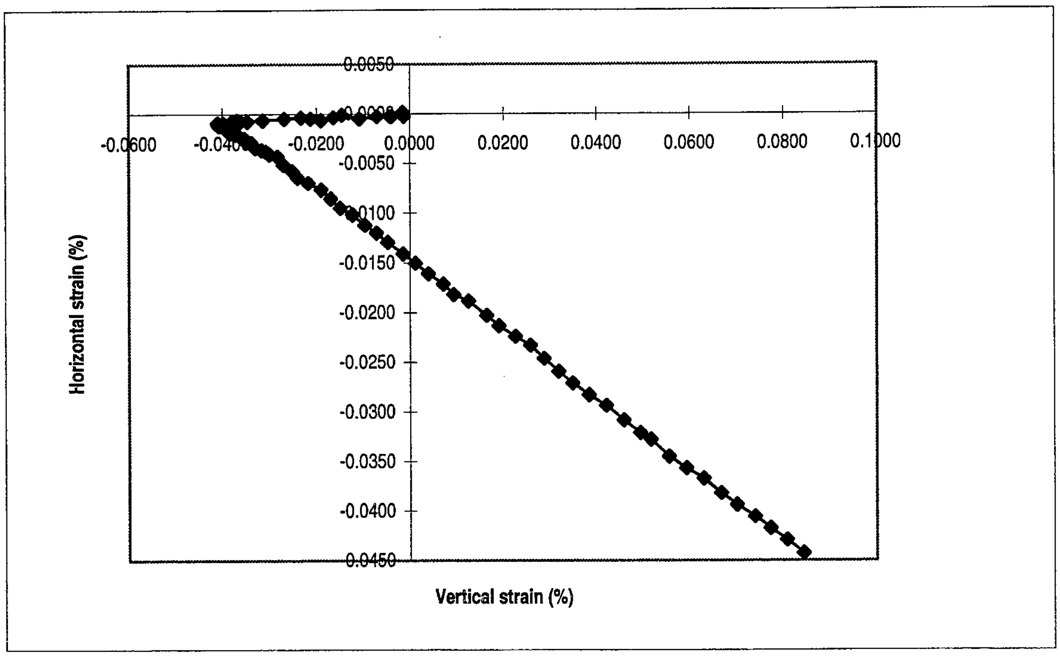
Checked

Approved

NGI

## Q-system parameters




| | |
|---|---|
| Uniaxial compressive strength: | 87.61 MPa |
| Deformation modulus: | 68.62 GPa |
| Poisson's ratio : | 0.348 |

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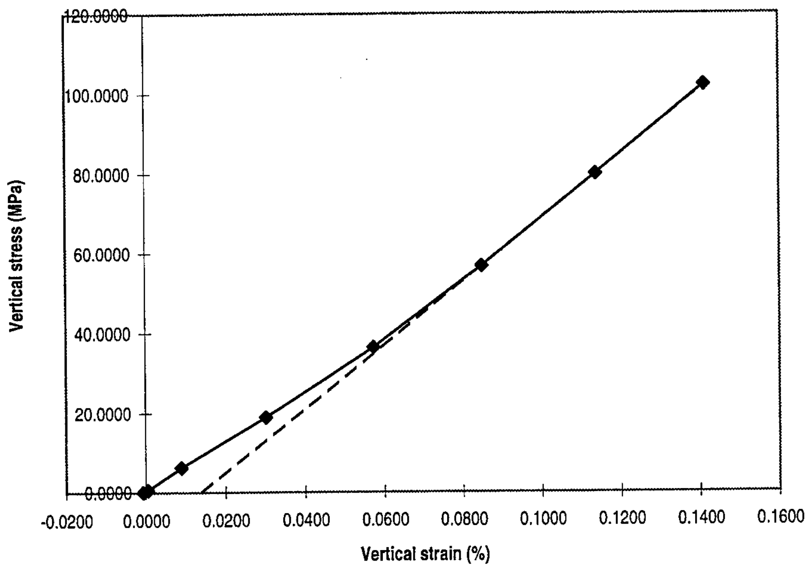
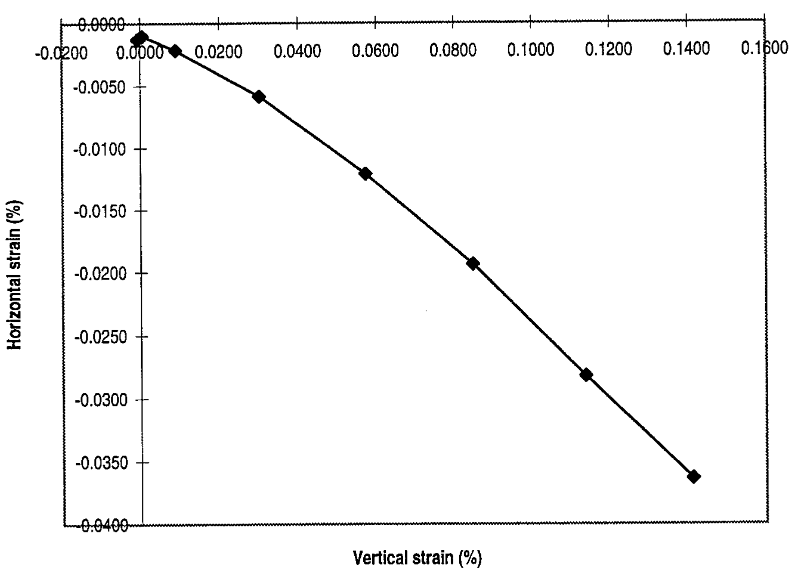
| | | | |
|---|---|---|---|
| **WES - TUNNEL CLOSURE EXPERIMENT** | | Report No. 923033-13 | Figure No. 10.1 |
| Unconfined Compression Test | Depth : 0.0 m | Drawn by PC | Date 04.02.97 |
| Boring : 0 | Tube : | Checked | NGI |
| Part : 0 | Test : 0 UCT No. : dummy | Approved | |




| | |
|---|---|
| Uniaxial compressive strength: | 102.12 MPa |
| Deformation modulus: | 80.06 GPa |
| Poisson's ratio : | 0.306 |

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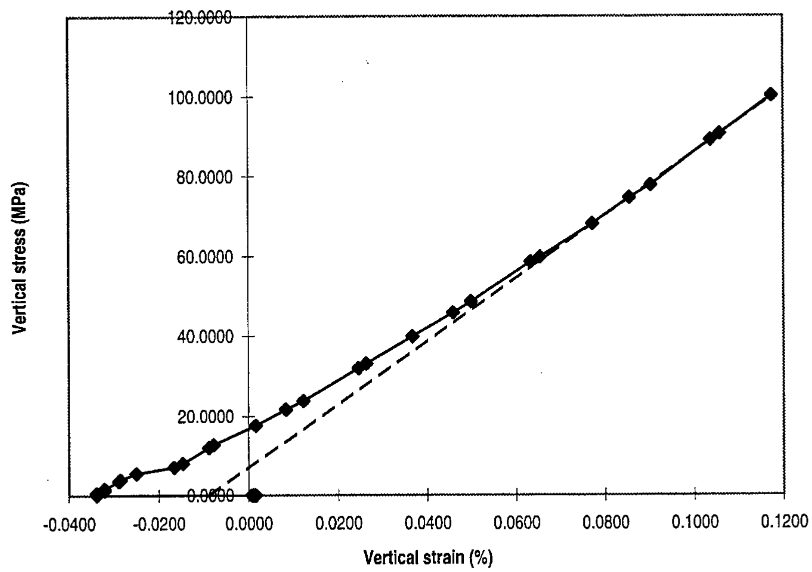
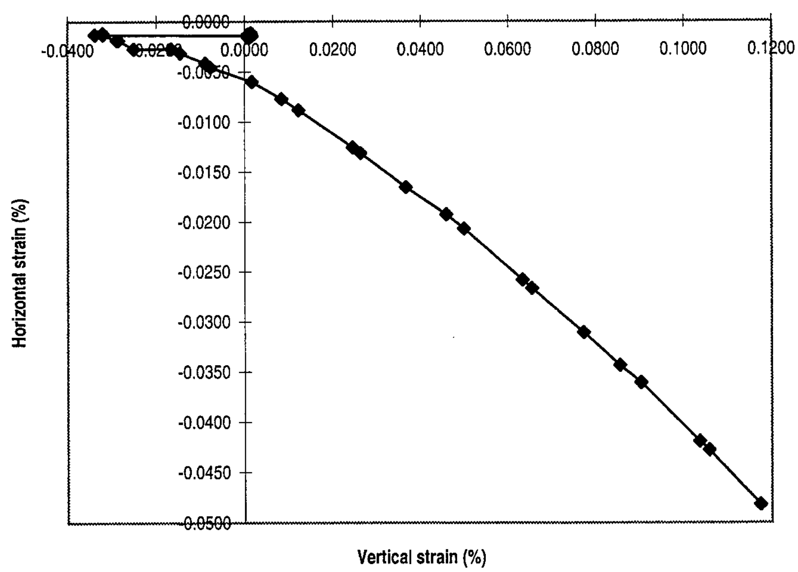
| | | | | |
|---|---|---|---|---|
| **WES - TUNNEL CLOSURE EXPERIMENT** | | | Report No. 923033-13 | Figure No. 10.2 |
| Unconfined Compression Test | | Depth : 7.1 m | Drawn by PC | Date 13.12.96 |
| Boring : 97/1 | Tube : | | Checked | NGI |
| Part : 1 | Test : 1 | UCT No. : 352 | Approved | |




| | |
|---|---|
| Uniaxial compressive strength: | 100.10 MPa |
| Deformation modulus: | 78.97 GPa |
| Poisson's ratio : | 0.413 |

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**WES - TUNNEL CLOSURE EXPERIMENT**

Report No. 923033-13 | Figure No. 10.3

Unconfined Compression Test | Depth : 9.2 m

Drawn by PC | Date 13.12.96

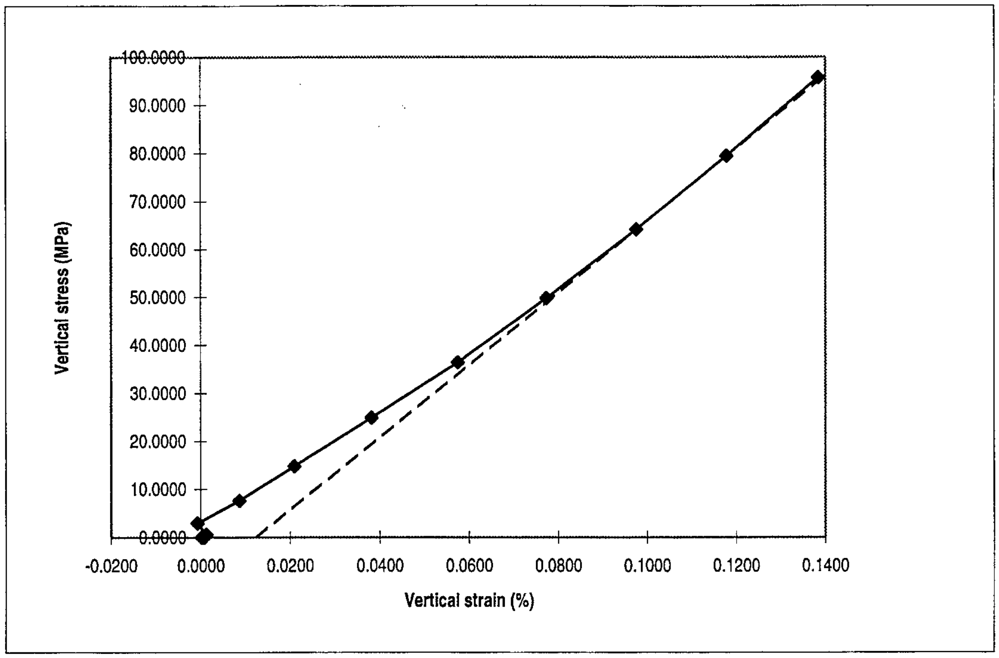
Boring : 97/1 | Tube :

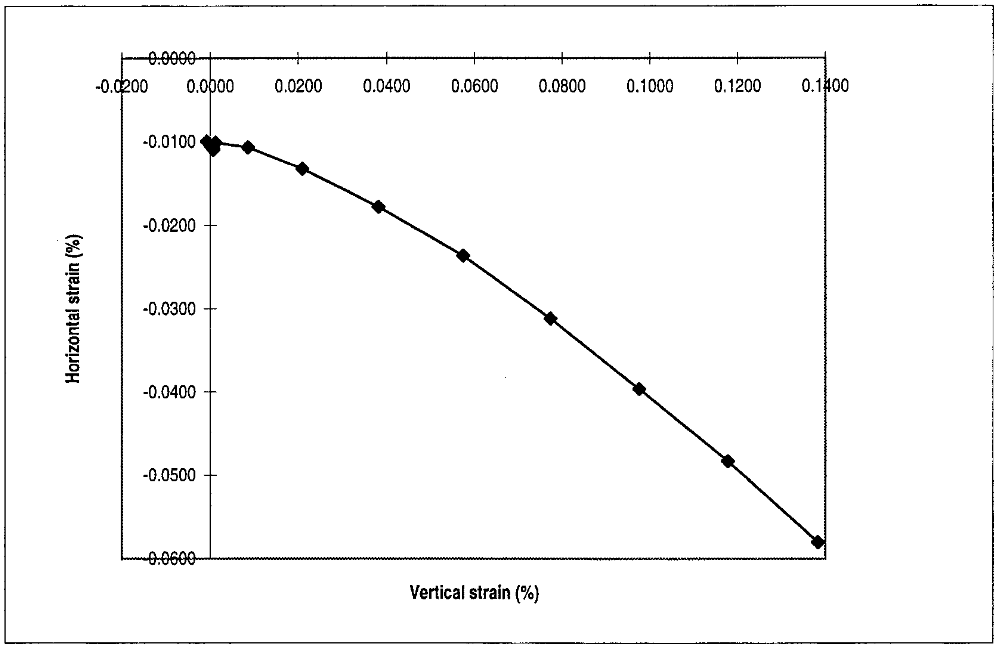
Checked

Approved

Part : 2 | Test : 2 | UCT No. : 353

NGI




| | |
|---|---|
| Uniaxial compressive strength: | 95.72 MPa |
| Deformation modulus: | 75.29 GPa |
| Poisson's ratio : | 0.430 |

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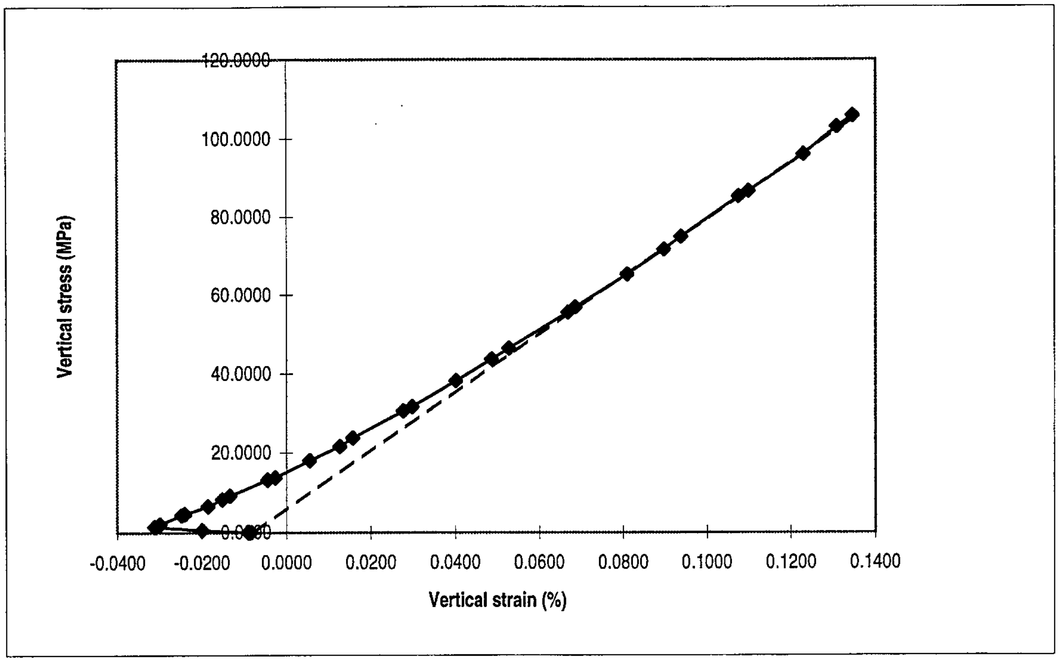
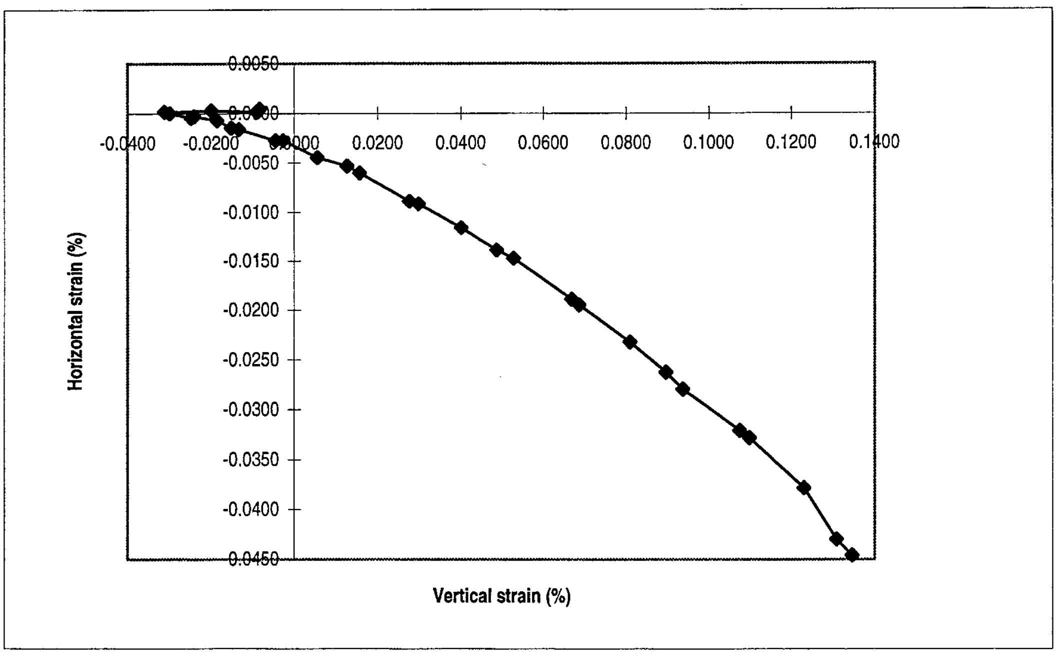
|---|---|---|---|---|---|
| **WES - TUNNEL CLOSURE EXPERIMENT** | | | | Report No. 923033-13 | Figure No. 10.4 |
| Unconfined Compression Test | | Depth : | 9.3 m | Drawn by PC | Date 18.12.96 |
| Boring : 97/1 | Tube : | | | Checked | NGI |
| Part : 3 | Test : 3 | UCT No. : 354 | | Approved | |




| | |
|---|---|
| Uniaxial compressive strength: | 105.77 MPa |
| Deformation modulus: | 73.58 GPa |
| Poisson's ratio : | 0.343 |

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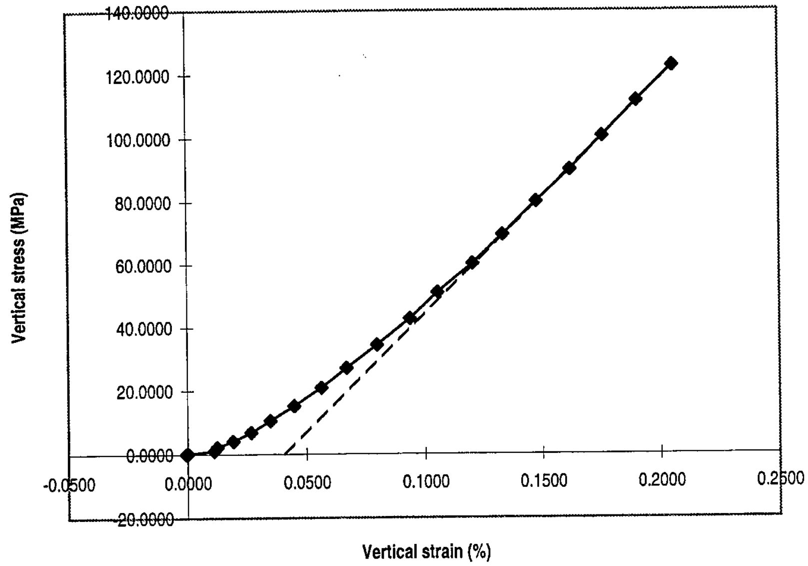
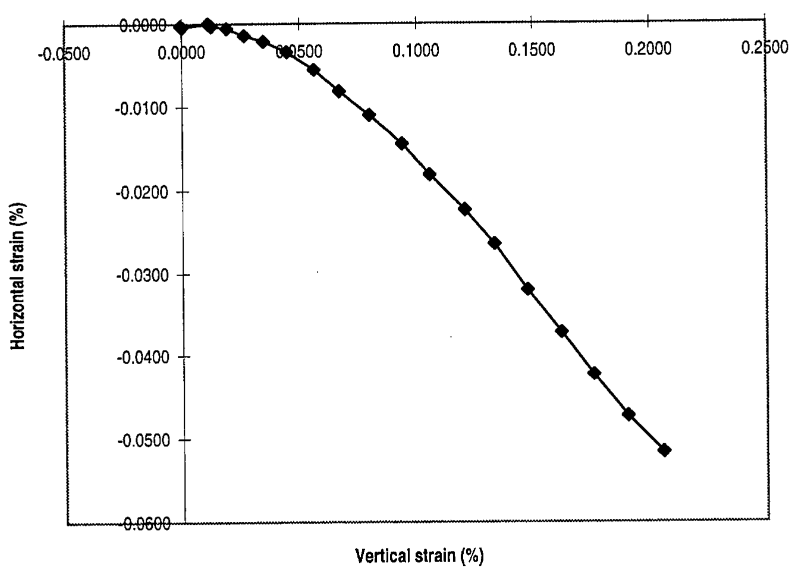
|---|---|---|
| **WES - TUNNEL CLOSURE EXPERIMENT** | Report No. 923033-13 | Figure No. 10.5 |
| Unconfined Compression Test    Depth : 10.4 m | Drawn by PC | Date 18.12.96 |
| Boring : 97/1    Tube : | Checked | NGI |
| Part : 4    Test : 4    UCT No. : 355 | Approved | |

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|---|---|
| Uniaxial compressive strength: | 122.56 MPa |
| Deformation modulus: | 74.41 GPa |
| Poisson's ratio : | 0.361 |

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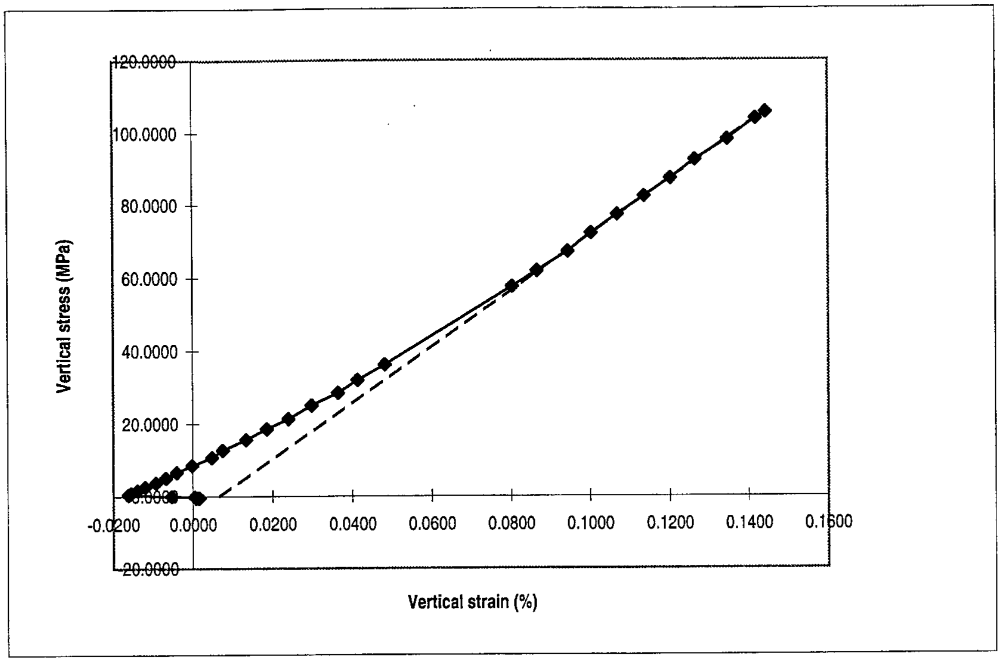
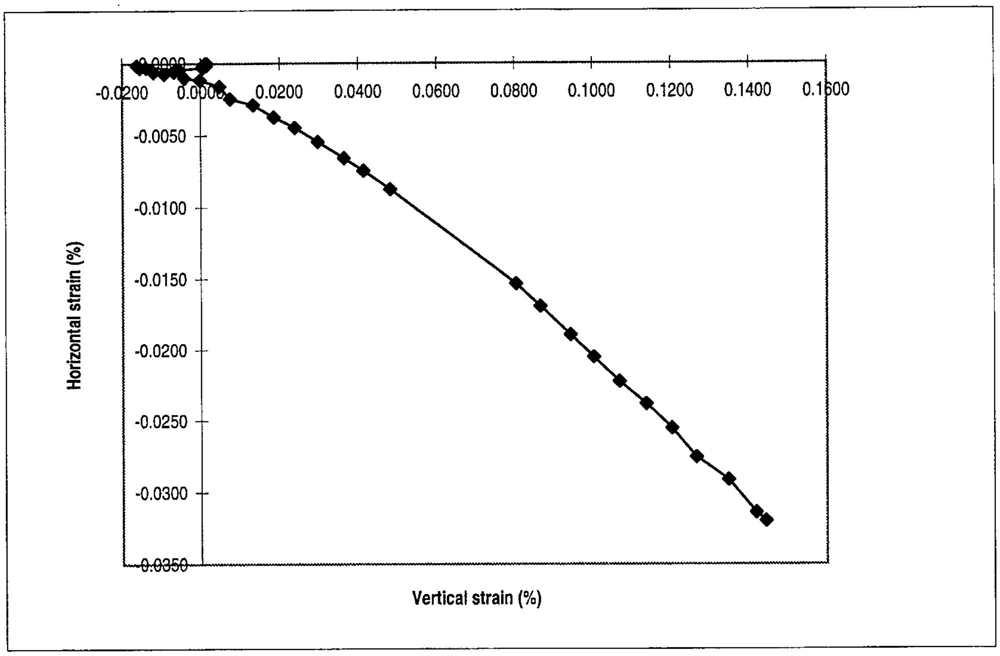
| **WES - TUNNEL CLOSURE EXPERIMENT** | | Report No. 923033-13 | Figure No. 10.6 |
| Unconfined Compression Test | Depth : 10.6 m | Drawn by PC | Date 19.12.96 |
| Boring : 97/1 | Tube : | Checked | |
| Part : 5 | Test : 5   UCT No. : 356 | Approved | NGI |

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|---|---|
| Uniaxial compressive strength: | 105.57 MPa |
| Deformation modulus: | 76.79 GPa |
| Poisson's ratio : | 0.257 |

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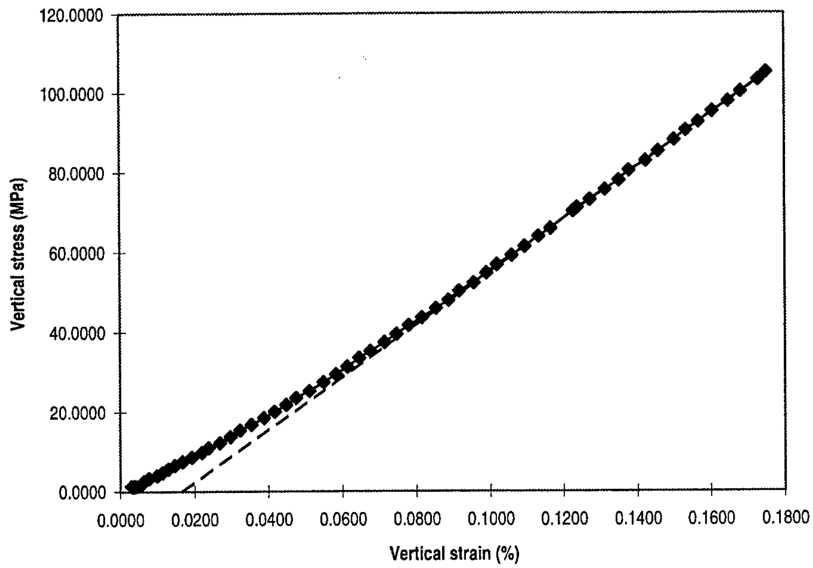
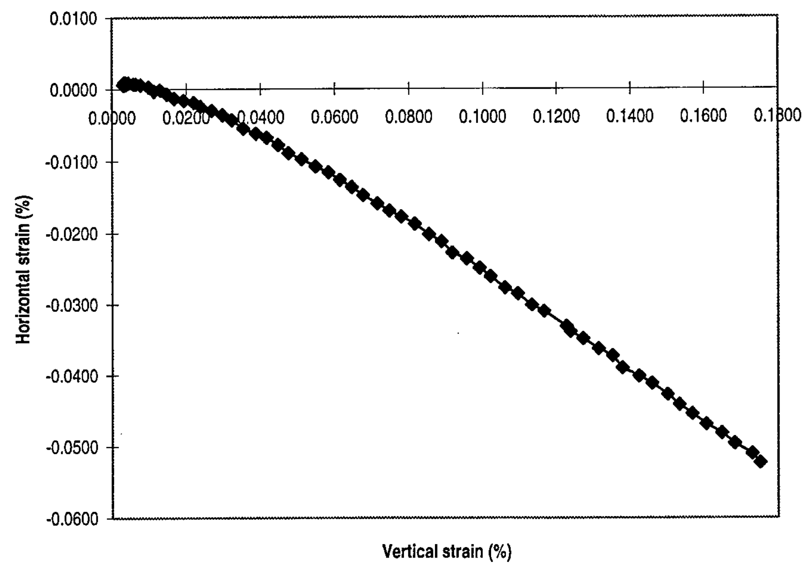
| **WES - TUNNEL CLOSURE EXPERIMENT** | Report No. 923033-13 | Figure No. 10.7 |
| Unconfined Compression Test — Depth : 17.1 m | Drawn by PC | Date 23.12.96 |
| Boring : 97/2 — Tube : | Checked | NGI |
| Part : 2 — Test : 7 — UCT No. : 358 | Approved | |

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| Uniaxial compressive strength: | 105.11 MPa |
| Deformation modulus: | 66.13 GPa |
| Poisson's ratio : | 0.355 |

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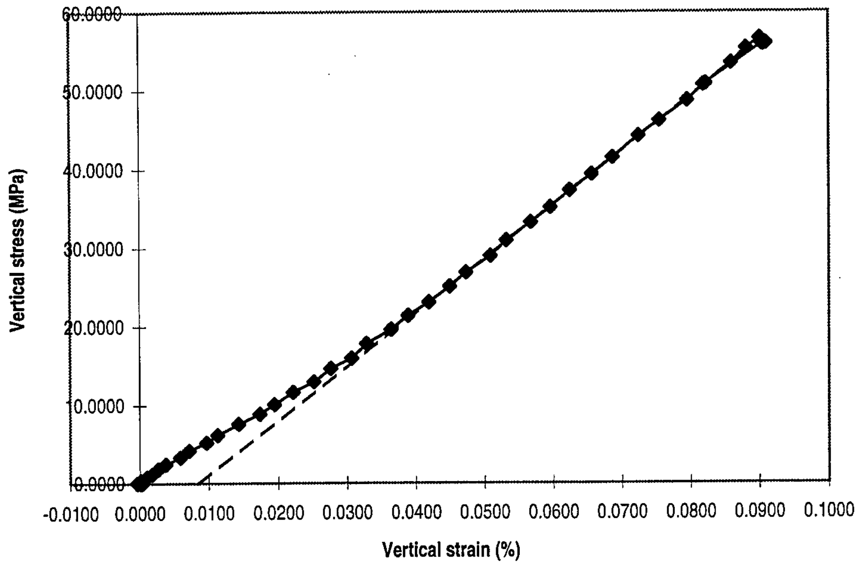
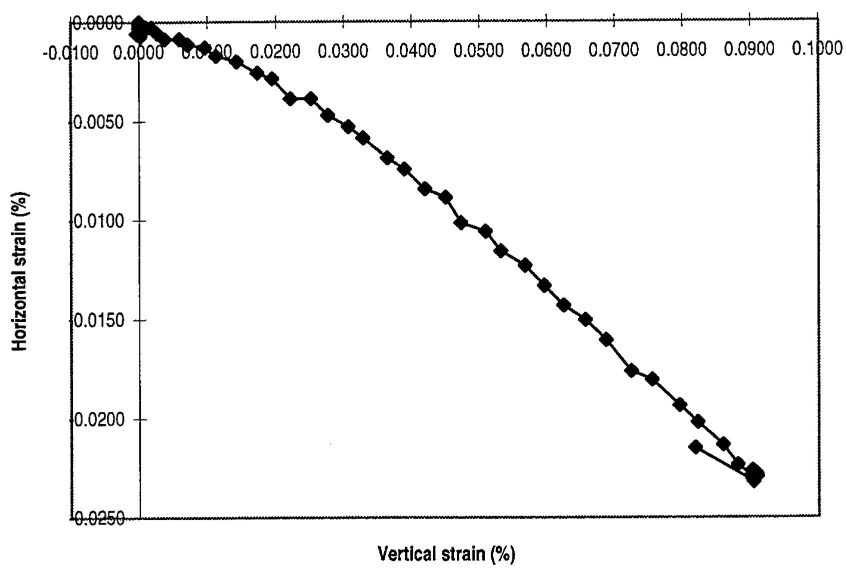
| | | Report No. | Figure No. |
|---|---|---|---|
| **WES - TUNNEL CLOSURE EXPERIMENT** | | 923033-13 | 10.8 |
| | | Drawn by | Date |
| Unconfined Compression Test | Depth : 19.2 m | PC | 13.01.97 |
| Boring : 97/2 | Tube : | Checked | |
| Part : 3 | Test : 8 UCT No. : 359 | Approved | NGI |

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| Uniaxial compressive strength: | 56.56 MPa |
| Deformation modulus: | 68.83 GPa |
| Poisson's ratio : | 0.304 |

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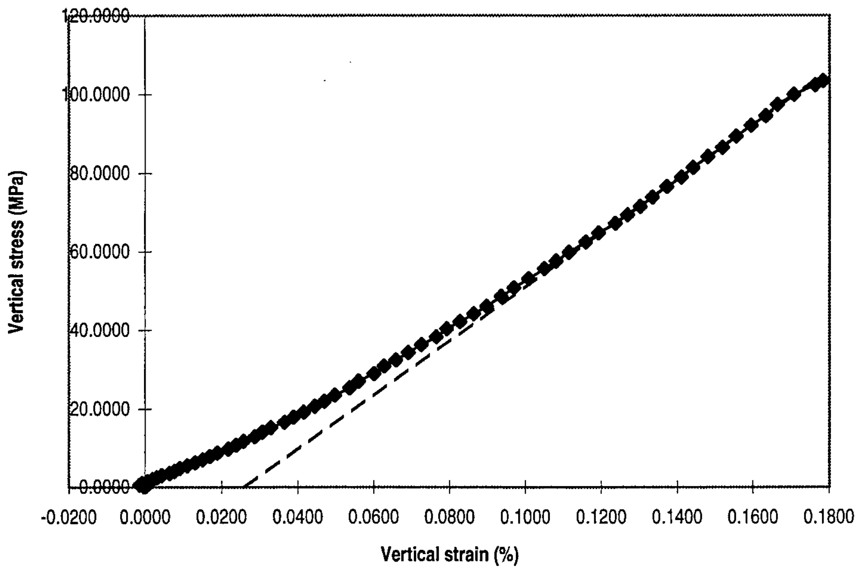
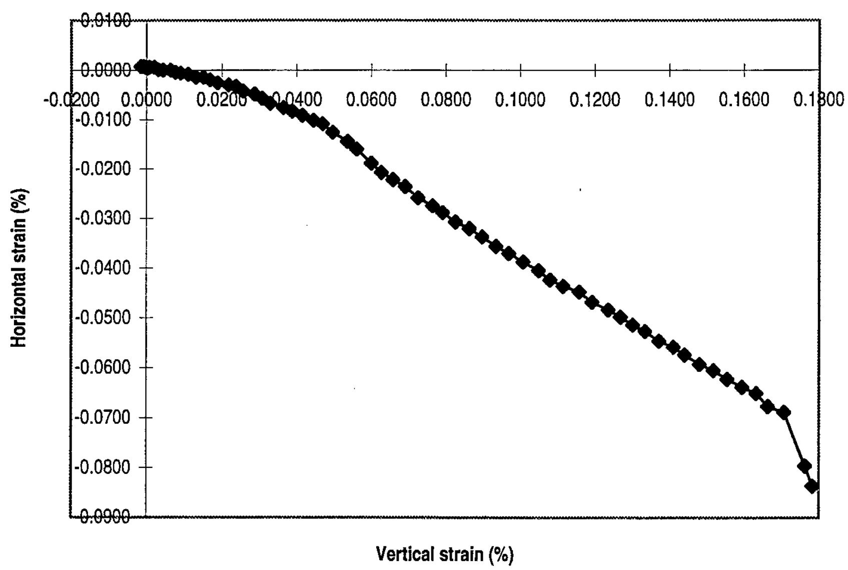
|---|---|---|---|---|---|
| **WES - TUNNEL CLOSURE EXPERIMENT** | | | | Report No. 923033-13 | Figure No. 10.9 |
| Unconfined Compression Test | | Depth : | 19.4 m | Drawn by PC | Date 10.12.96 |
| Boring : 97/2 | Tube : | | | Checked | NGI |
| Part : 4 | Test : 9 | UCT No. : 360 | | Approved | |

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|---|---|
| Uniaxial compressive strength: | 103.41 MPa |
| Deformation modulus: | 68.86 GPa |
| Poisson's ratio : | 0.436 |

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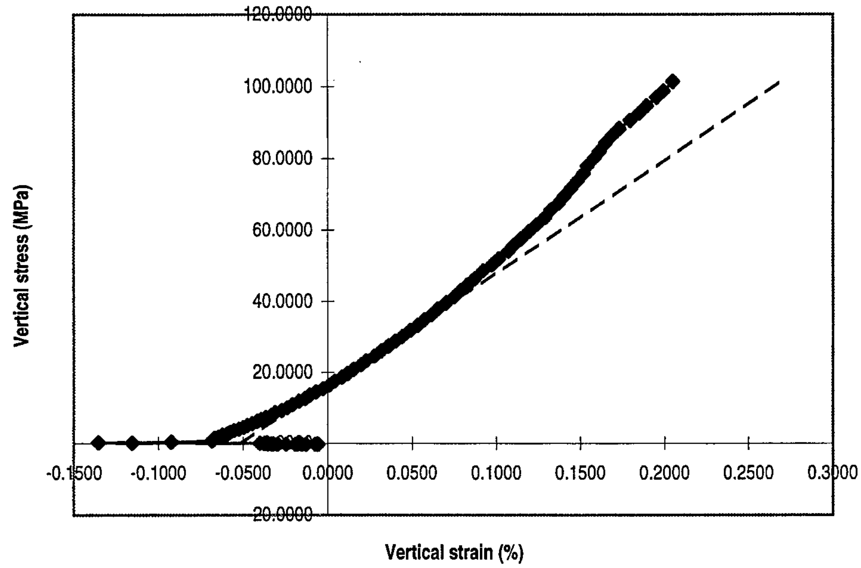
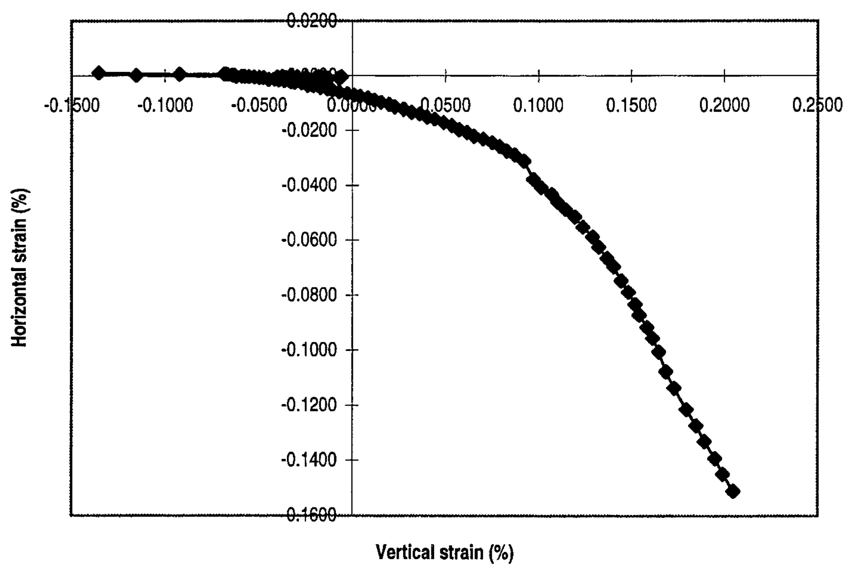
| **WES - TUNNEL CLOSURE EXPERIMENT** | Report No. 923033-13 | Figure No. 10.10 |
| Unconfined Compression Test    Depth : 19.5 m | Drawn by PC | Date 10.01.97 |
| Boring : 97/2    Tube : | Checked | NGI |
| Part : 5    Test : 10    UCT No. : 361 | Approved | |

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|---|---|
| Uniaxial compressive strength: | 101.37 MPa |
| Deformation modulus: | 31.58 GPa |
| Poisson's ratio : | 0.213 |

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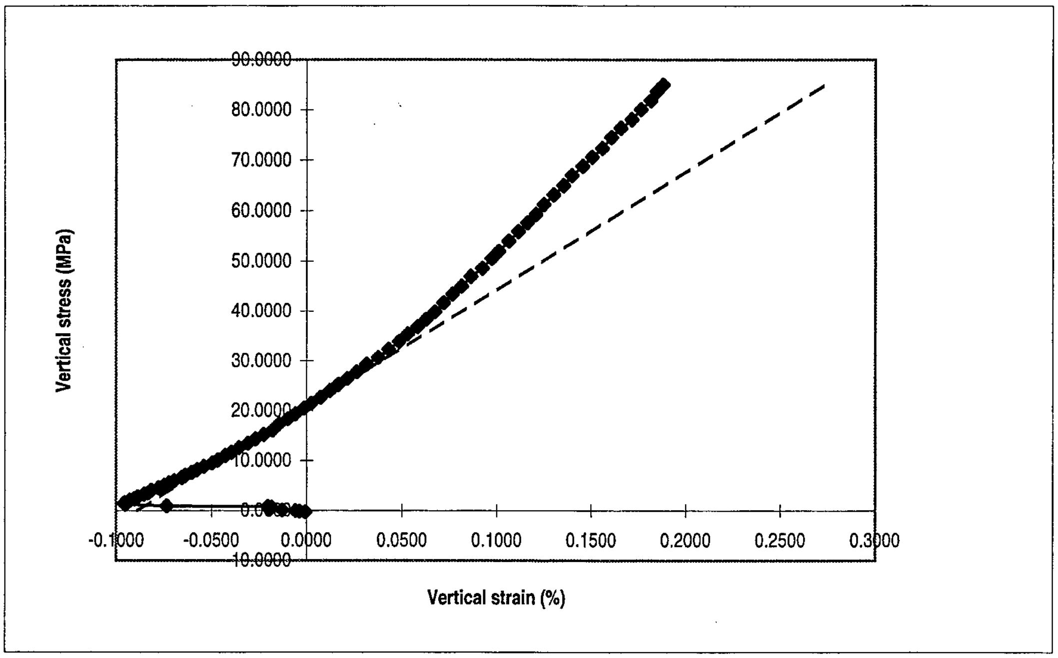
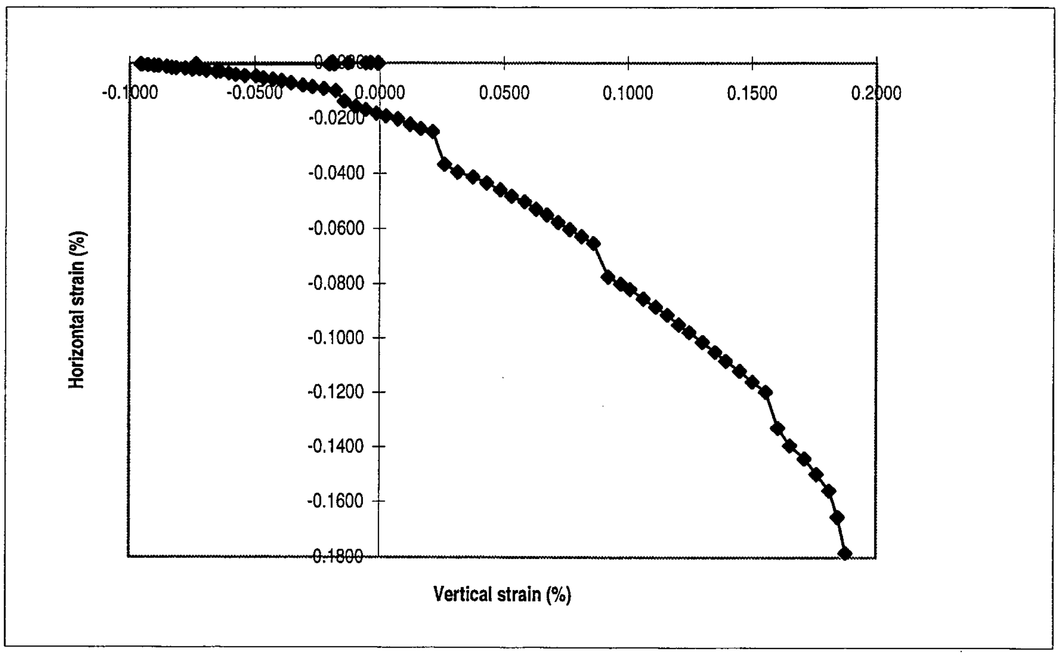
| **WES - TUNNEL CLOSURE EXPERIMENT** | Report No. 923033-13 | Figure No. 10.11 |
| Unconfined Compression Test Depth : 10.7 m | Drawn by PC | Date 10.01.97 |
| Boring : 97/3 Tube : | Checked | NGI |
| Part : 1 Test : 11 UCT No. : 362 | Approved | |

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|---|---|
| Uniaxial compressive strength: | 85.02 MPa |
| Deformation modulus: | 23.42 GPa |
| Poisson's ratio : | 0.298 |

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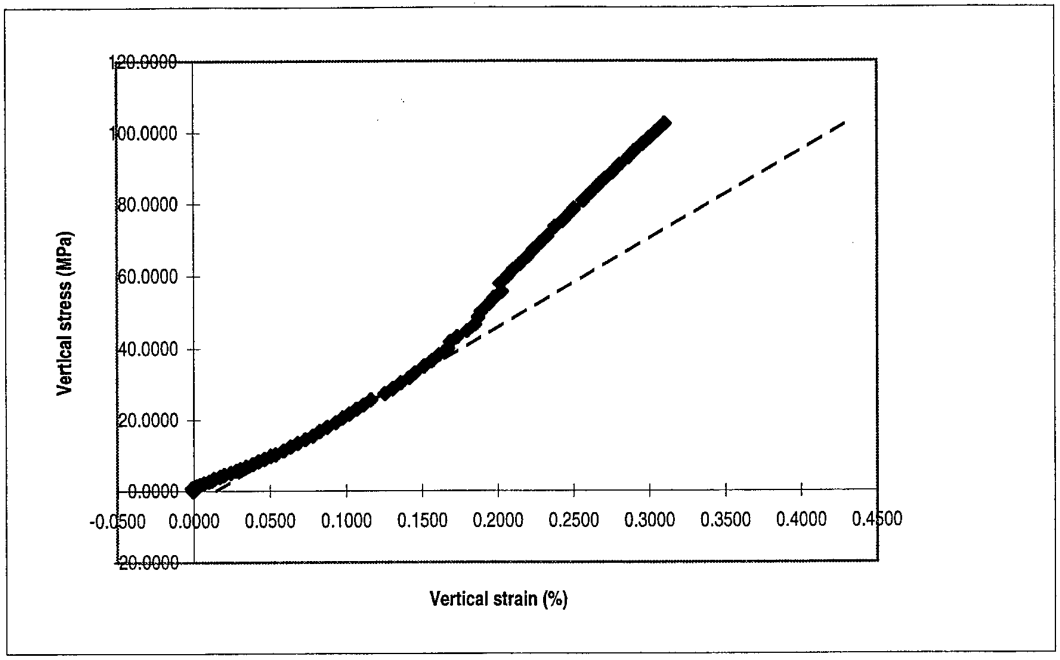
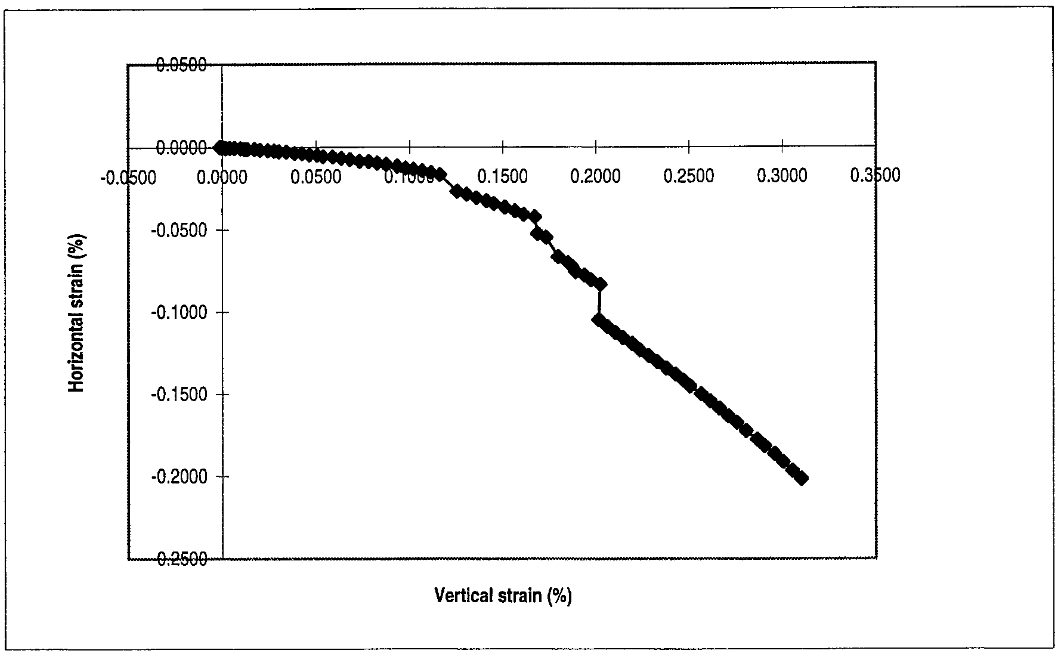
| **WES - TUNNEL CLOSURE EXPERIMENT** | Report No. 923033-13 | Figure No. 10.12 |
| Unconfined Compression Test    Depth : 13.2 m | Drawn by PC | Date 17.01.97 |
| Boring : 97/3    Tube : | Checked | NGI |
| Part : 2    Test : 12    UCT No. : 363 | Approved | |




| | |
|---|---|
| Uniaxial compressive strength: | 102.42 MPa |
| Deformation modulus: | 24.67 GPa |
| Poisson's ratio : | 0.371 |

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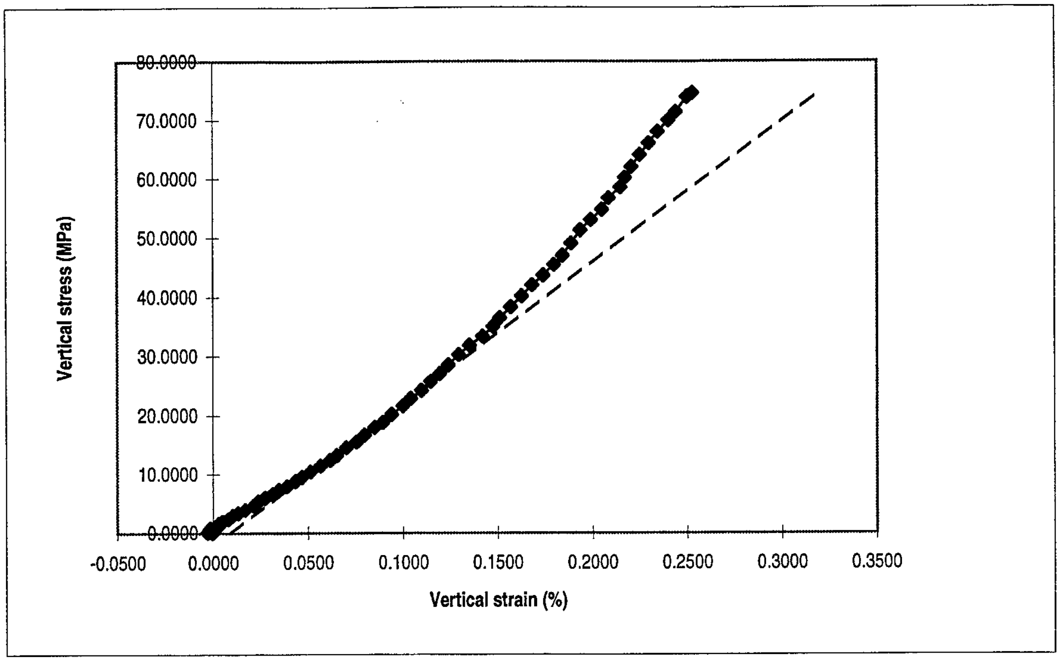
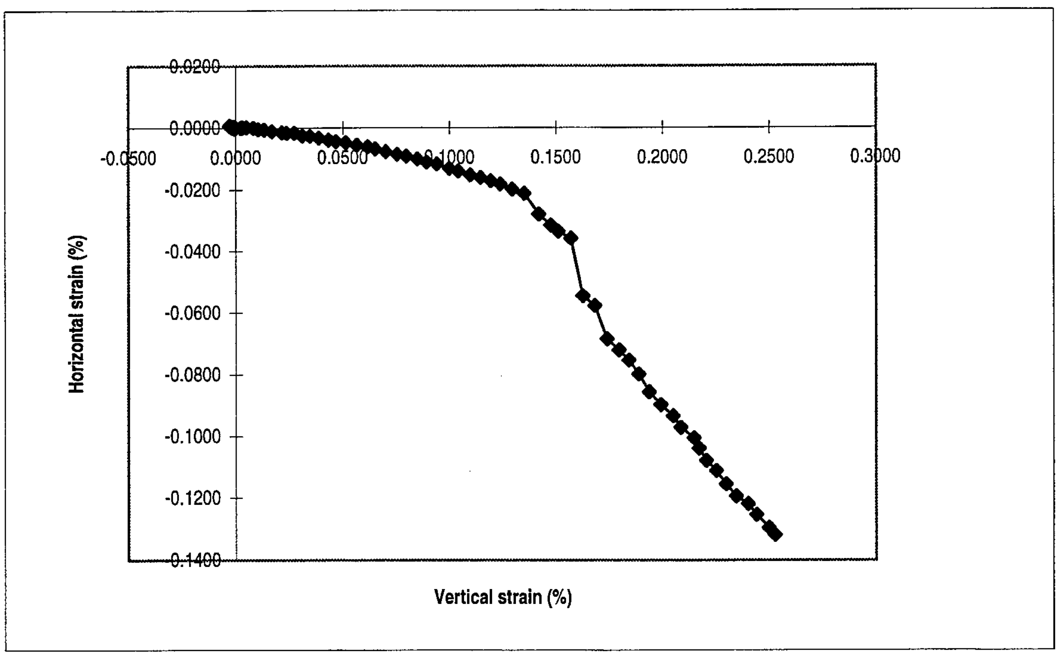
| **WES - TUNNEL CLOSURE EXPERIMENT** | | Report No. 923033-13 | Figure No. 10.13 |
| Unconfined Compression Test | Depth : 17.4 m | Drawn by PC | Date 20.01.97 |
| Boring : 97/3 | Tube : | Checked | |
| Part : 3 | Test : 13 UCT No. : 364 | Approved | NGI |




| | |
|---|---|
| Uniaxial compressive strength: | 74.60 MPa |
| Deformation modulus: | 24.01 GPa |
| Poisson's ratio : | 0.177 |

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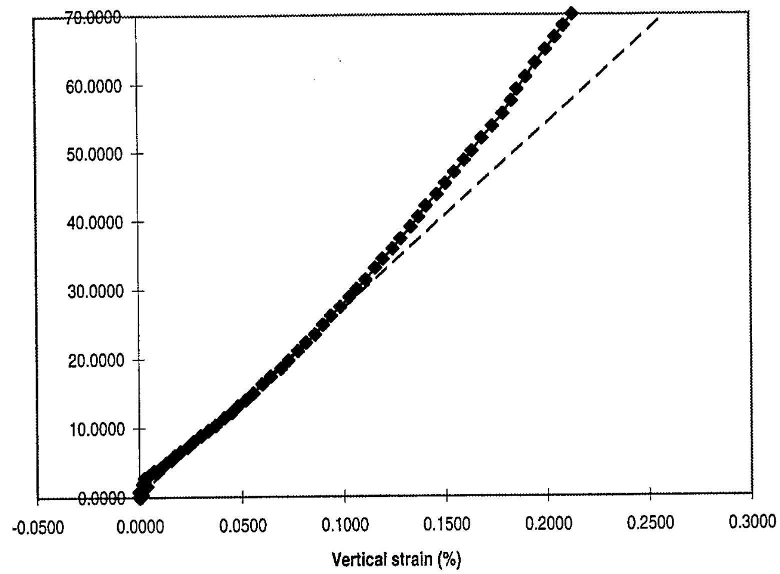
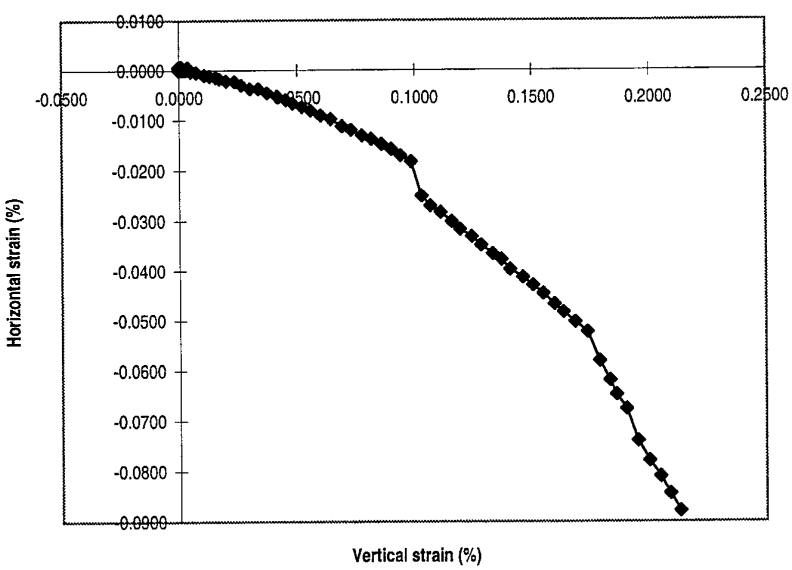
| **WES - TUNNEL CLOSURE EXPERIMENT** | | | Report No. 923033-13 | Figure No. 10.14 |
| Unconfined Compression Test | | Depth : 17.5 m | Drawn by PC | Date 20.01.97 |
| Boring : 97/3 | Tube : | | Checked | NGI |
| Part : 4 | Test : 14 | UCT No. : 365 | Approved | |

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|---|---|
| Uniaxial compressive strength: | 69.99 MPa |
| Deformation modulus: | 26.86 GPa |
| Poisson's ratio : | 0.211 |

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**WES - TUNNEL CLOSURE EXPERIMENT**

Report No. 923033-13

Figure No. 10.15

Unconfined Compression Test

Depth : 17.7 m

Drawn by PC

Date 20.01.97

Boring : 97/3

Tube :

Checked

Approved

Part : 5

Test : 15

UCT No. : 366

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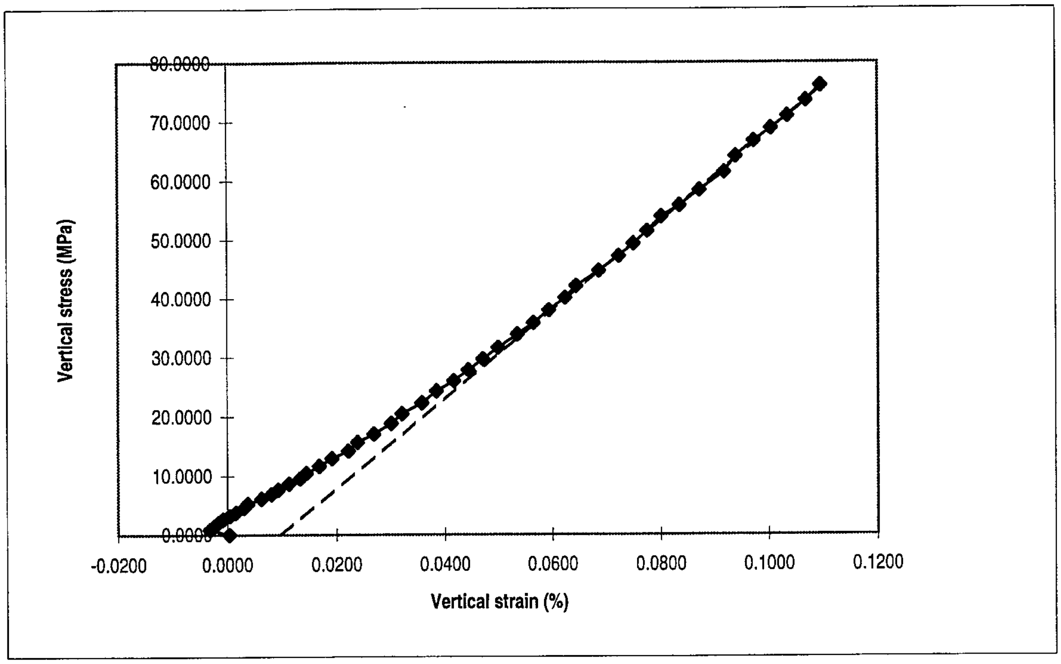


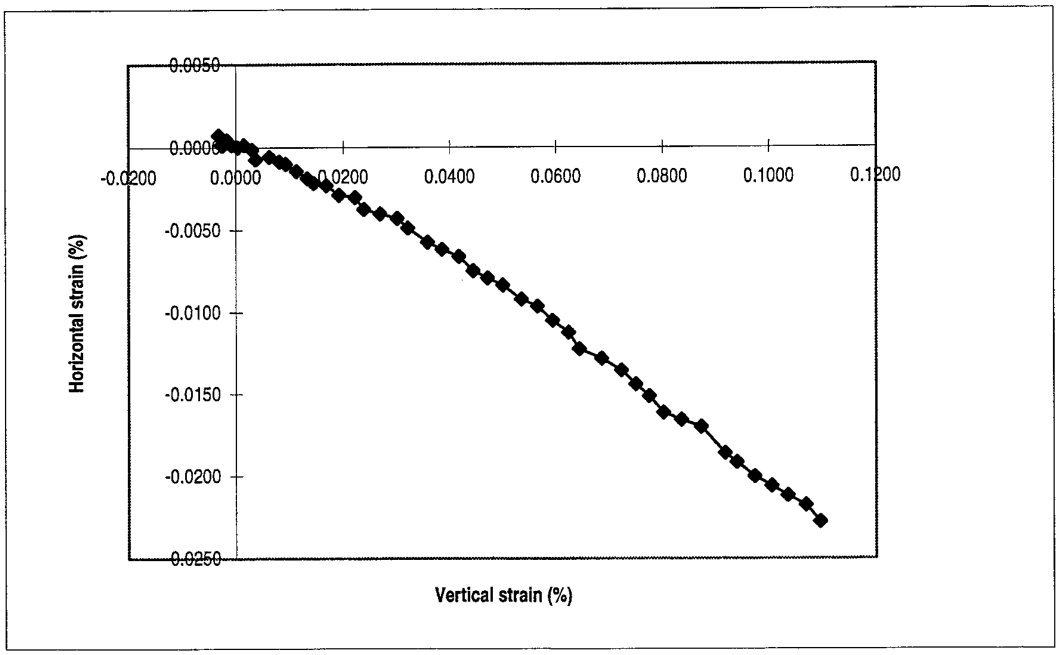


| | |
|---|---|
| Uniaxial compressive strength: | 76.05 MPa |
| Deformation modulus: | 75.69 GPa |
| Poisson's ratio : | 0.244 |

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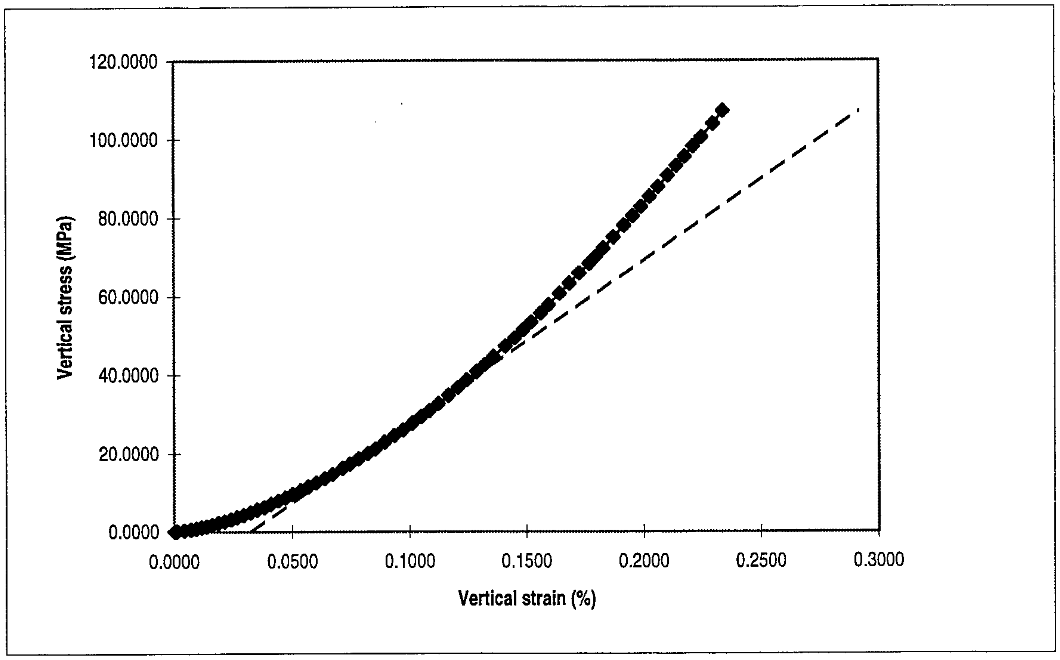
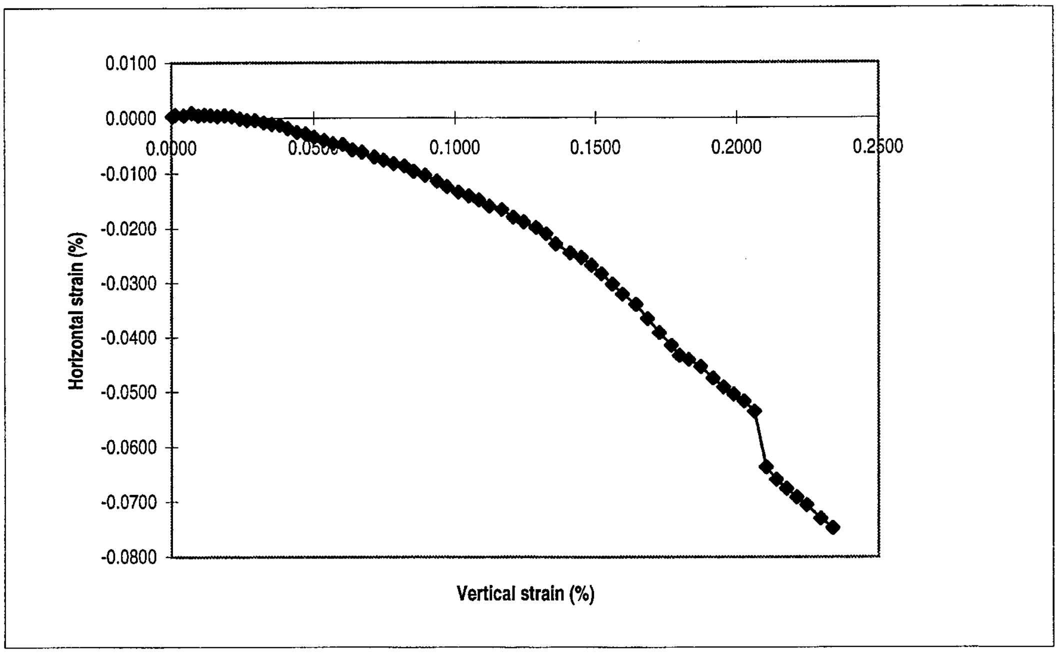
| **WES - TUNNEL CLOSURE EXPERIMENT** | Report No. 923033-13 | Figure No. 10.16 |
| Unconfined Compression Test Depth : 14.1 m | Drawn by PC | Date 20.01.97 |
| Boring : 97/5 Tube : | Checked | NGI |
| Part : 1 Test : 16 UCT No. : 367 | Approved | |




| | |
|---|---|
| Uniaxial compressive strength: | 107.12 MPa |
| Deformation modulus: | 41.26 GPa |
| Poisson's ratio : | 0.220 |

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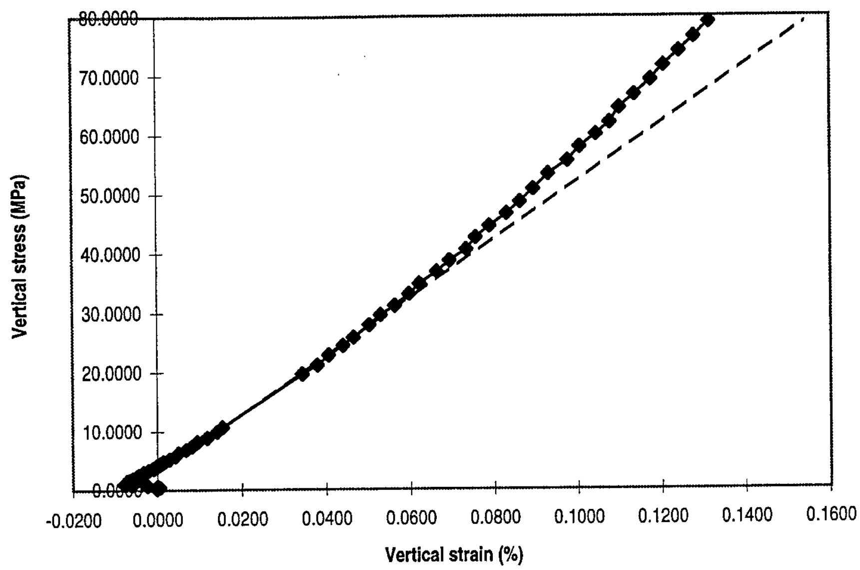
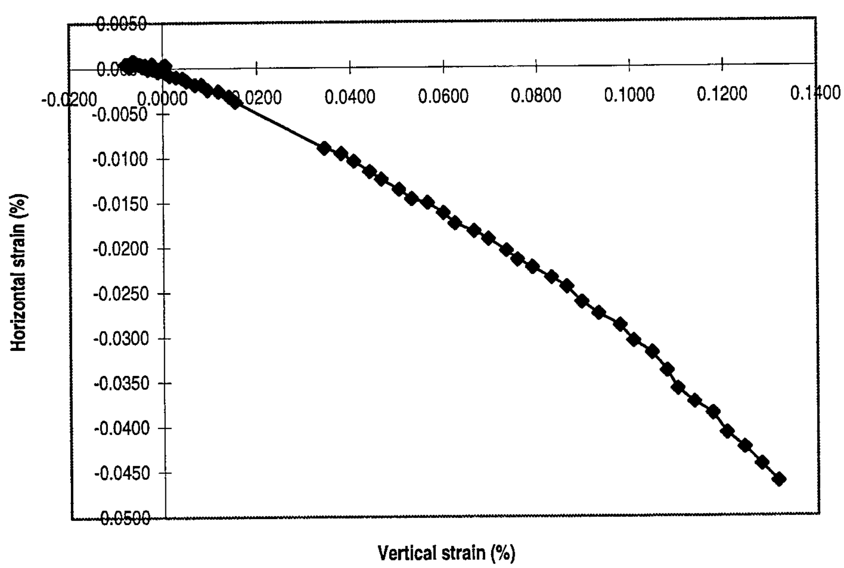
|---|---|---|
| **WES - TUNNEL CLOSURE EXPERIMENT** | Report No. 923033-13 | Figure No. 10.17 |
| Unconfined Compression Test Depth : 14.2 m | Drawn by PC | Date 20.01.97 |
| Boring : 97/5 Tube : | Checked | NGI |
| Part : 2 Test : 17 UCT No. : 368 | Approved | |

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|---|---|
| Uniaxial compressive strength: | 78.99 MPa |
| Deformation modulus: | 49.25 GPa |
| Poisson's ratio : | 0.280 |

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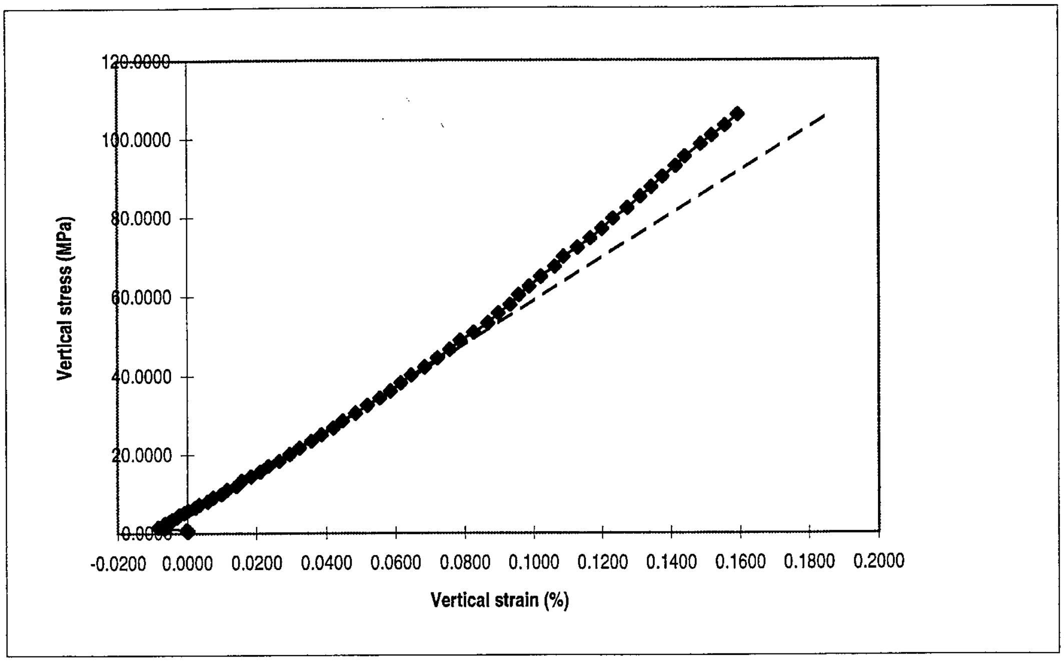
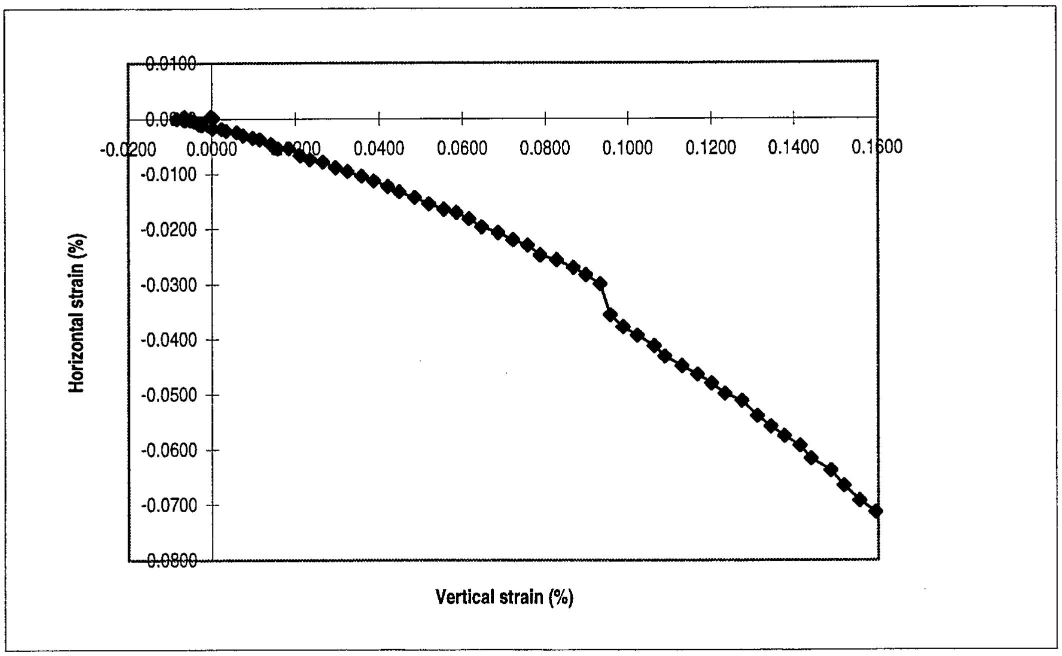
|---|---|---|
| **WES - TUNNEL CLOSURE EXPERIMENT** | Report No. 923033-13 | Figure No. 10.18 |
| Unconfined Compression Test    Depth : 14.8 m | Drawn by PC | Date 20.01.97 |
| Boring : 97/5    Tube : | Checked | NGI |
| Part : 3    Test : 18    UCT No. : 369 | Approved | |

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|---|---|
| Uniaxial compressive strength: | 106.06 MPa |
| Deformation modulus: | 54.86 GPa |
| Poisson's ratio : | 0.293 |

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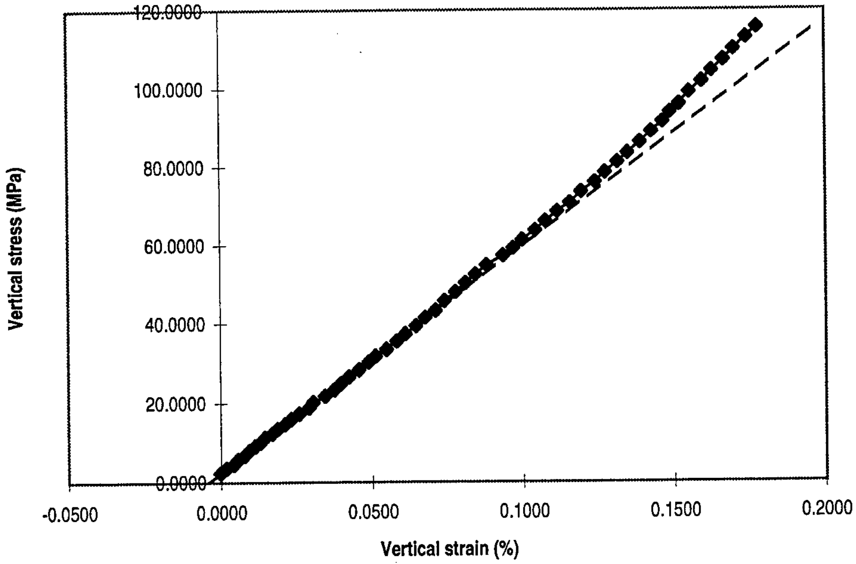
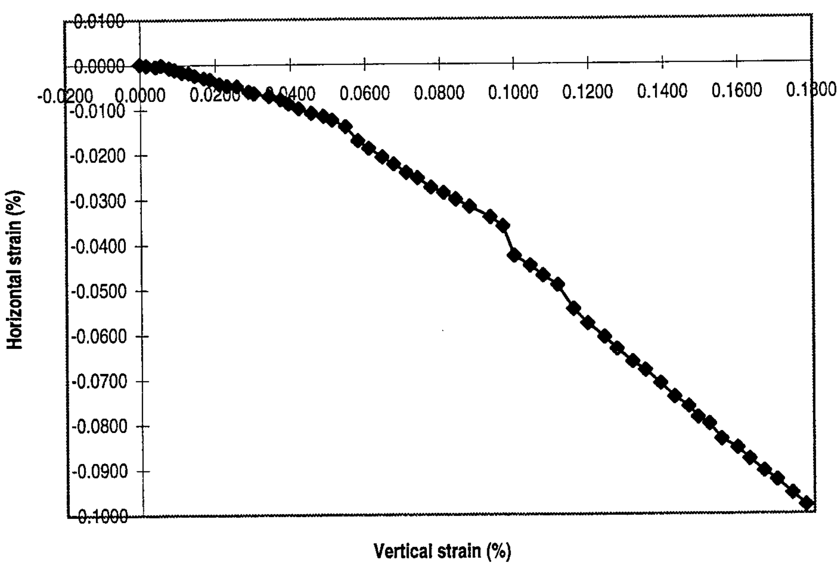
| **WES - TUNNEL CLOSURE EXPERIMENT** | | | Report No. 923033-13 | Figure No. 10.19 |
| Unconfined Compression Test | | Depth : 14.9 m | Drawn by PC | Date 21.01.97 |
| Boring : 97/5 | Tube : | | Checked | NGI |
| Part : 4 | Test : 19 | UCT No. : 370 | Approved | |

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|---|---|
| Uniaxial compressive strength: | 115.55 MPa |
| Deformation modulus: | 57.51 GPa |
| Poisson's ratio : | 0.406 |

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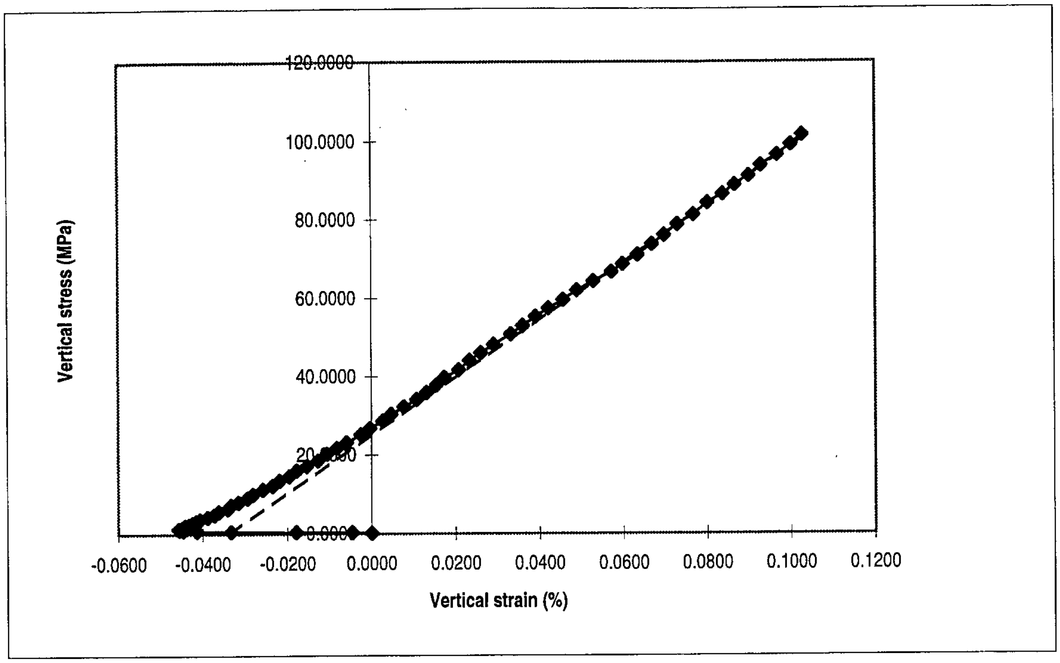
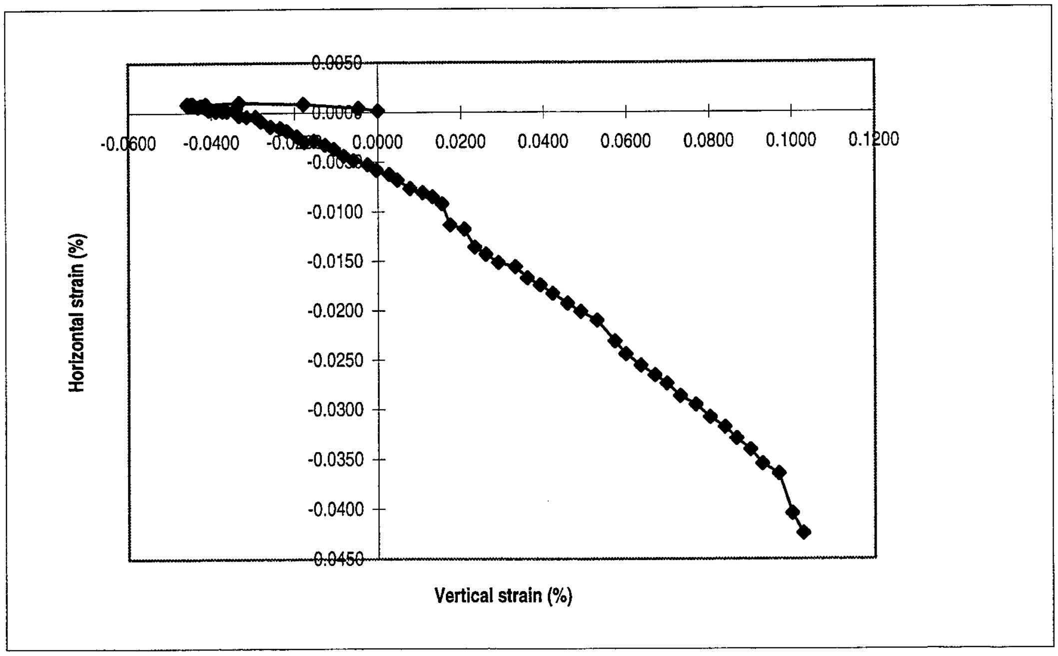
| **WES - TUNNEL CLOSURE EXPERIMENT** | | Report No. 923033-13 | Figure No. 10.20 |
| Unconfined Compression Test | Depth : 15.2 m | Drawn by PC | Date 20.01.97 |
| Boring : 97/5 | Tube : | Checked | |
| Part : 5 | Test : 20 UCT No. : 371 | Approved | NGI |

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|---|---|
| Uniaxial compressive strength: | 101.47 MPa |
| Deformation modulus: | 73.52 GPa |
| Poisson's ratio : | 0.342 |

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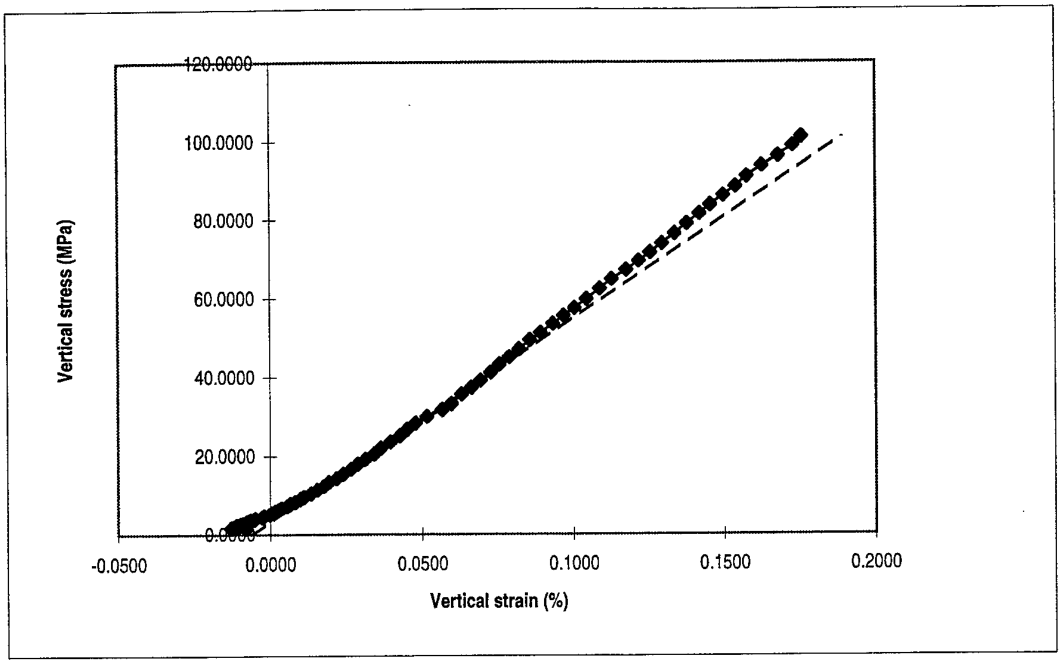
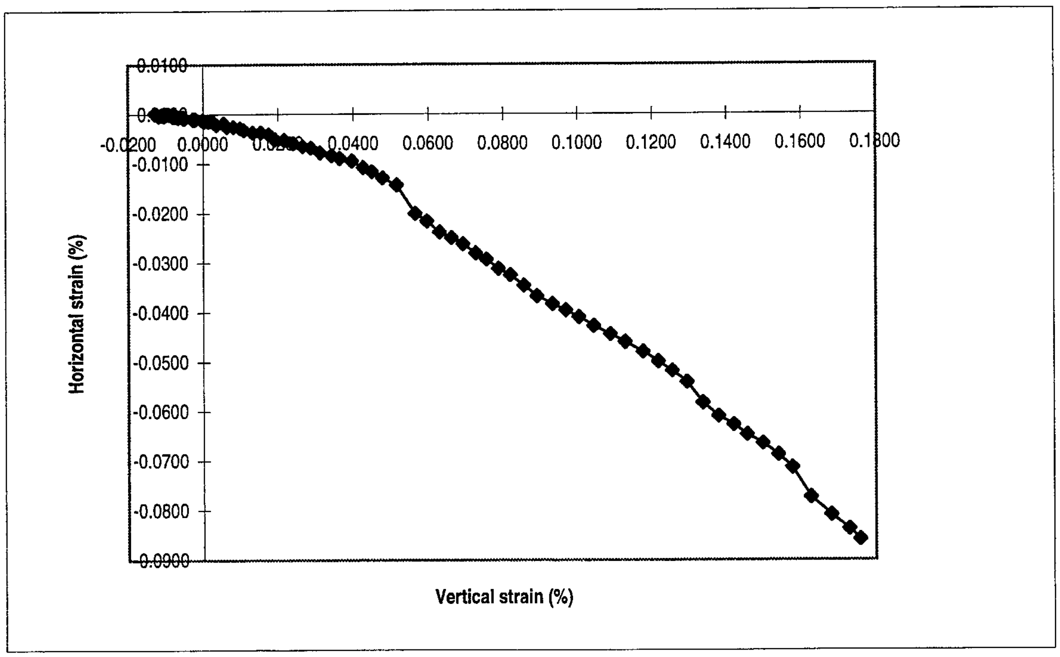
| **WES - TUNNEL CLOSURE EXPERIMENT** | Report No. 923033-13 | Figure No. 10.21 |
| Unconfined Compression Test — Depth : 10.5 m | Drawn by PC | Date 22.01.97 |
| Boring : 97/6 — Tube : | Checked | NGI |
| Part : 1 — Test : 21 — UCT No. : 372 | Approved | |

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|---|---|
| Uniaxial compressive strength: | 101.02 MPa |
| Deformation modulus: | 51.72 GPa |
| Poisson's ratio : | 0.277 |

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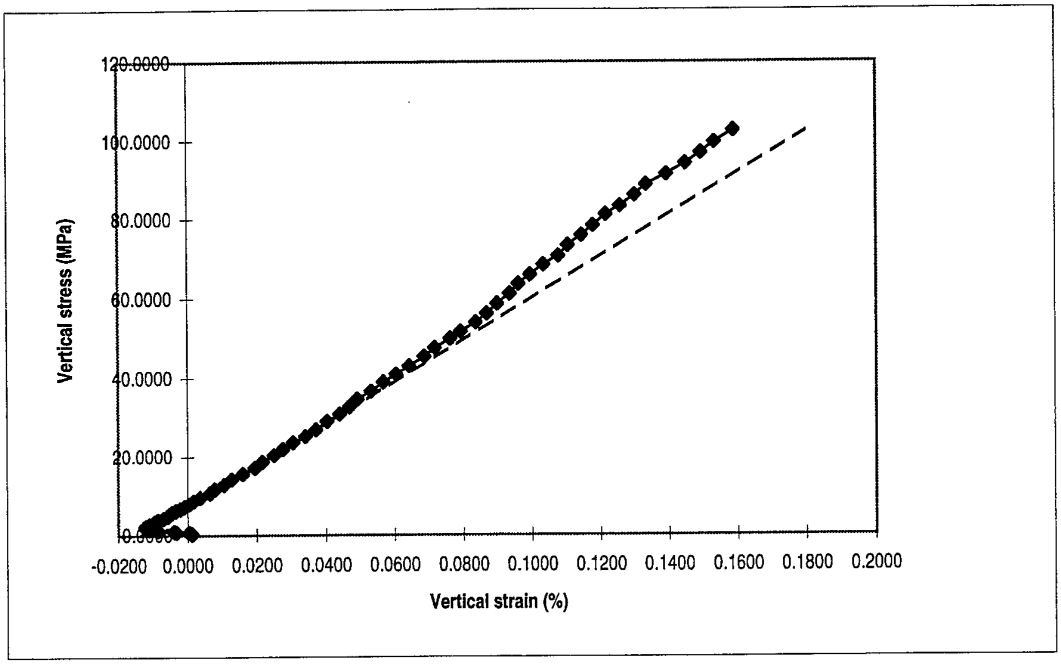
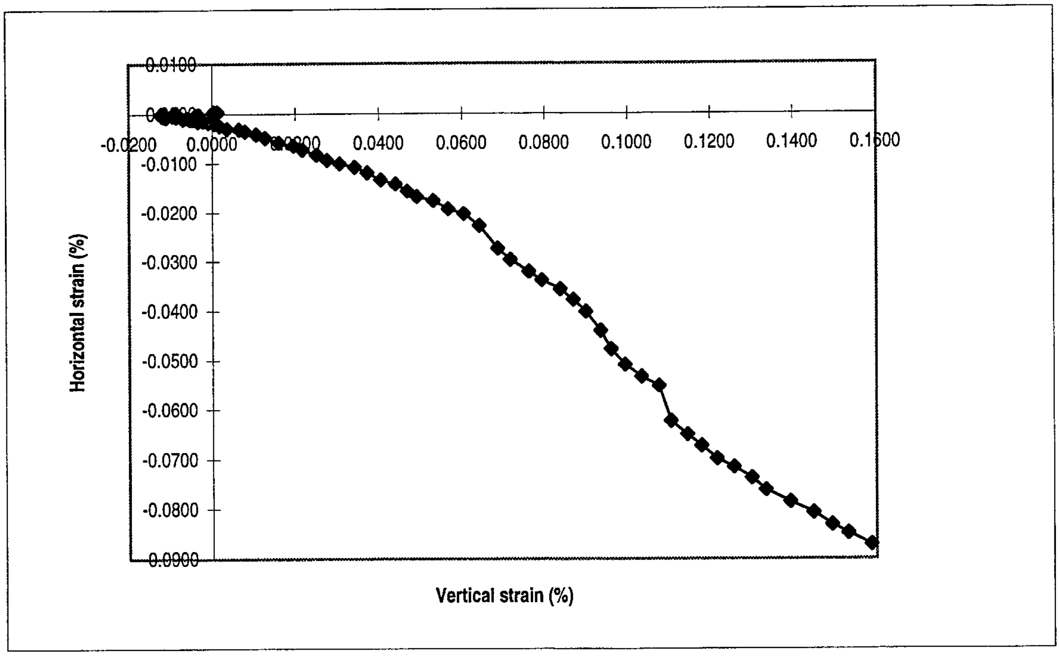
| **WES - TUNNEL CLOSURE EXPERIMENT** | | Report No. 923033-13 | Figure No. 10.22 |
| Unconfined Compression Test | Depth : 10.6 m | Drawn by PC | Date 22.01.97 |
| Boring : 97/6 | Tube : | Checked | NGI |
| Part : 2 | Test : 22   UCT No. : 373 | Approved | |

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|---|---|
| Uniaxial compressive strength: | 102.61 MPa |
| Deformation modulus: | 52.93 GPa |
| Poisson's ratio : | 0.296 |

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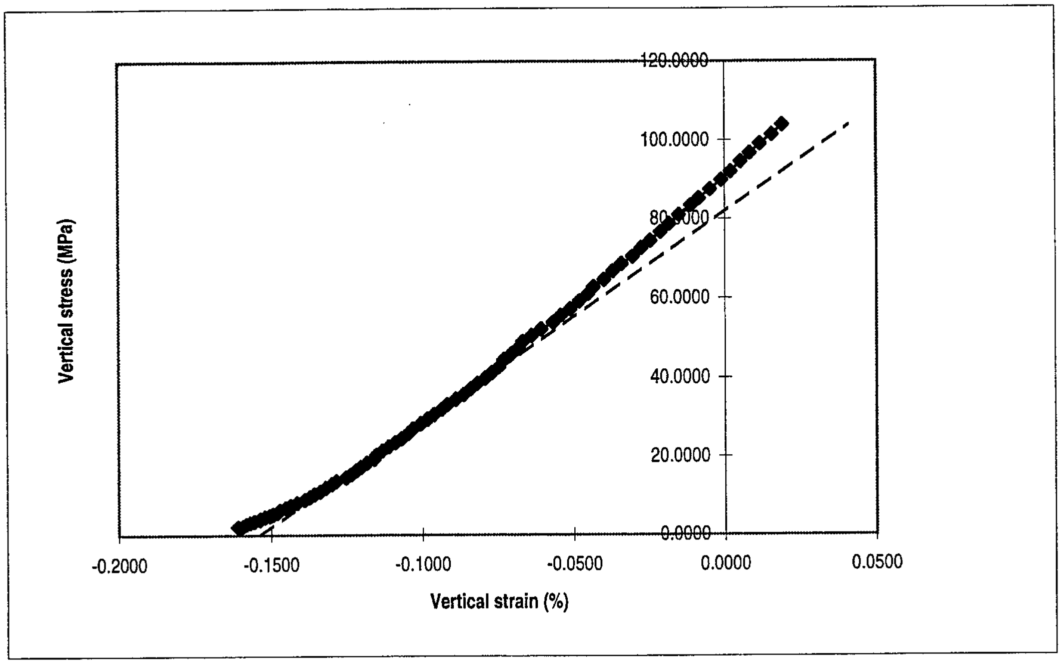
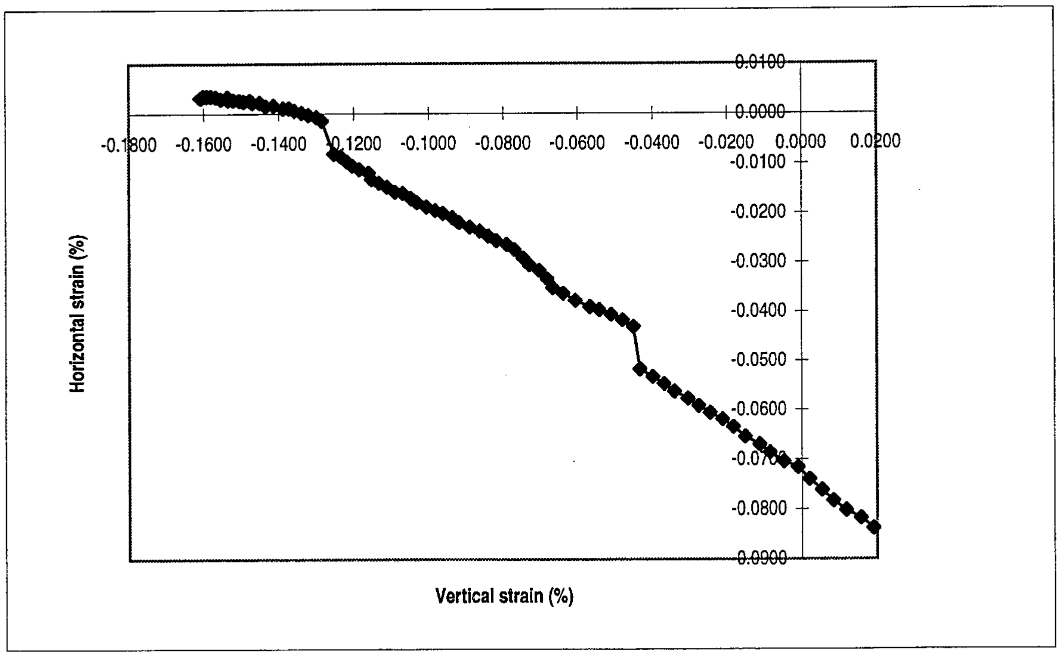
| **WES - TUNNEL CLOSURE EXPERIMENT** | | Report No. 923033-13 | Figure No. 10.23 |
| Unconfined Compression Test | Depth : 11.2 m | Drawn by PC | Date 24.01.97 |
| Boring : 97/6 | Tube : | Checked | NGI |
| Part : 3 | Test : 23 UCT No. : 374 | Approved | |

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|---|---|
| Uniaxial compressive strength: | 103.78 MPa |
| Deformation modulus: | 53.27 GPa |
| Poisson's ratio : | 0.240 |

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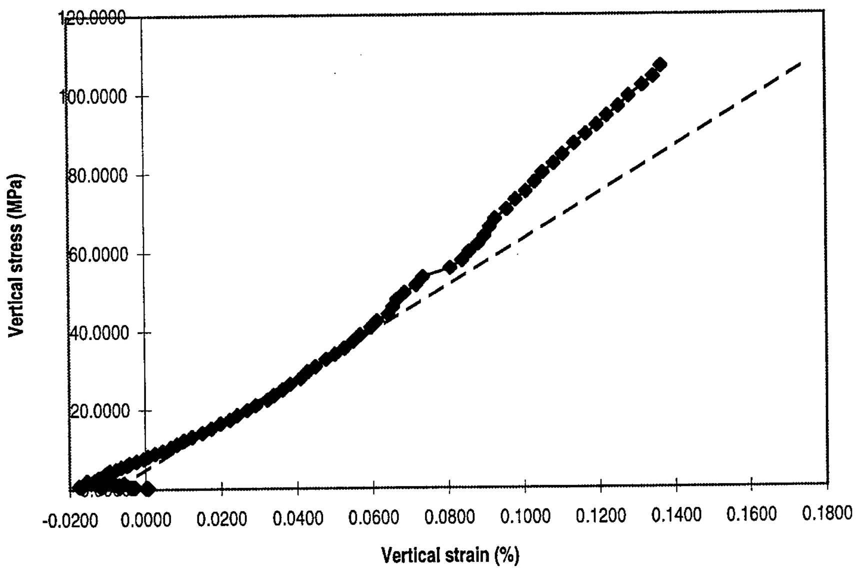
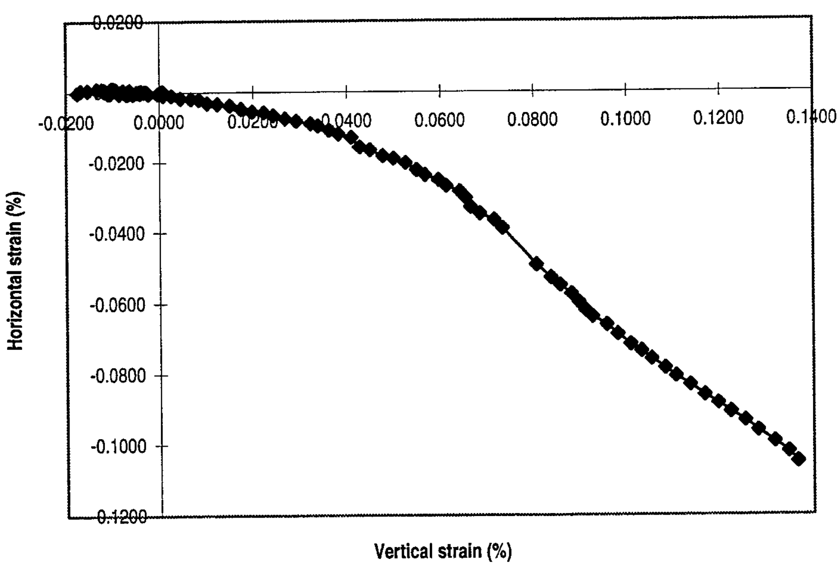
| **WES - TUNNEL CLOSURE EXPERIMENT** | Report No. 923033-13 | Figure No. 10.24 |
| Unconfined Compression Test    Depth : 11.8 m | Drawn by PC | Date 24.01.97 |
| Boring : 97/6    Tube : | Checked | NGI |
| Part : 5    Test : 25    UCT No. : 376 | Approved | |

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|---|---|
| Uniaxial compressive strength: | 106.74 MPa |
| Deformation modulus: | 58.49 GPa |
| Poisson's ratio : | 0.472 |

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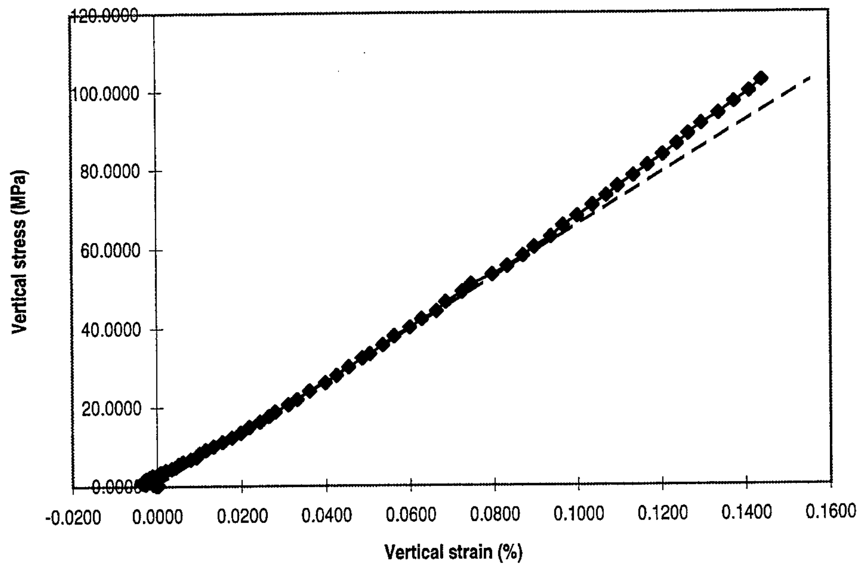
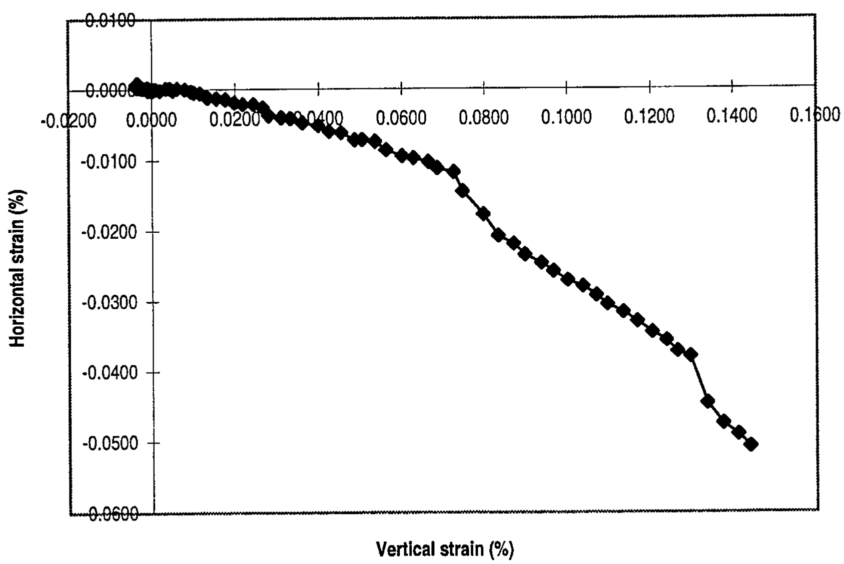
| **WES - TUNNEL CLOSURE EXPERIMENT** | | Report No. 923033-13 | Figure No. 10.25 |
| Unconfined Compression Test | Depth : 13.3 m | Drawn by PC | Date 24.01.97 |
| Boring : 97/7 | Tube : | Checked | NGI |
| Part : 1 | Test : 26 UCT No. : 377 | Approved | |

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|---|---|
| Uniaxial compressive strength: | 102.61 MPa |
| Deformation modulus: | 65.63 GPa |
| Poisson's ratio : | 0.184 |

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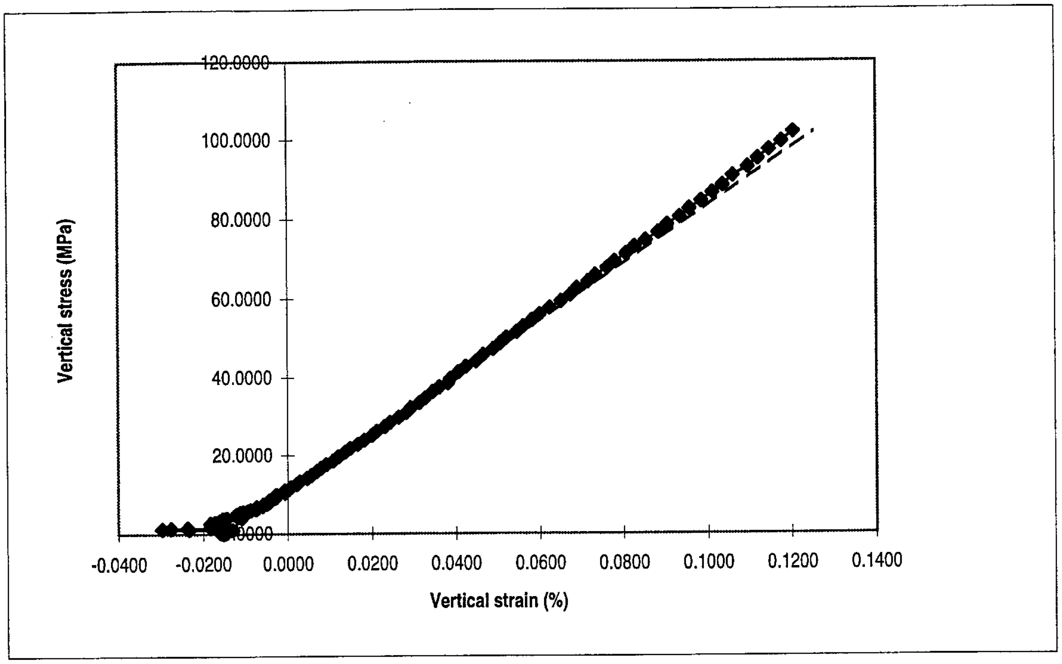
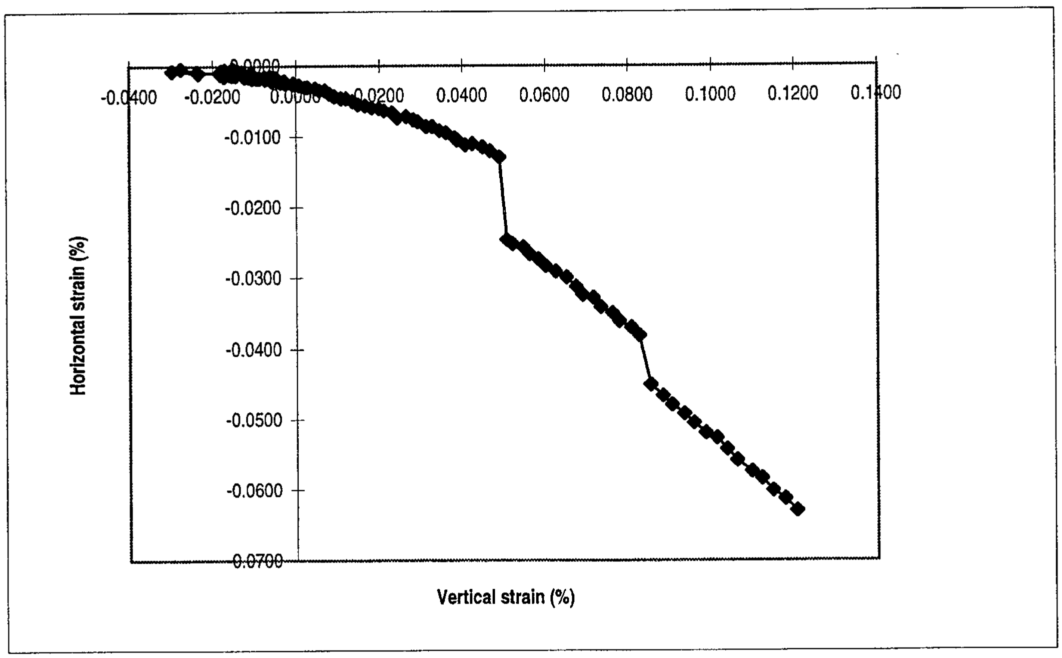
|---|---|---|
| **WES - TUNNEL CLOSURE EXPERIMENT** | Report No. 923033-13 | Figure No. 10.26 |
| Unconfined Compression Test Depth : 13.3 m | Drawn by PC | Date 24.01.97 |
| Boring : 97/7 Tube : | Checked | NGI |
| Part : 2 Test : 27 UCT No. : 378 | Approved | |

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|---|---|
| Uniaxial compressive strength: | 101.78 MPa |
| Deformation modulus: | 72.38 GPa |
| Poisson's ratio : | 0.197 |

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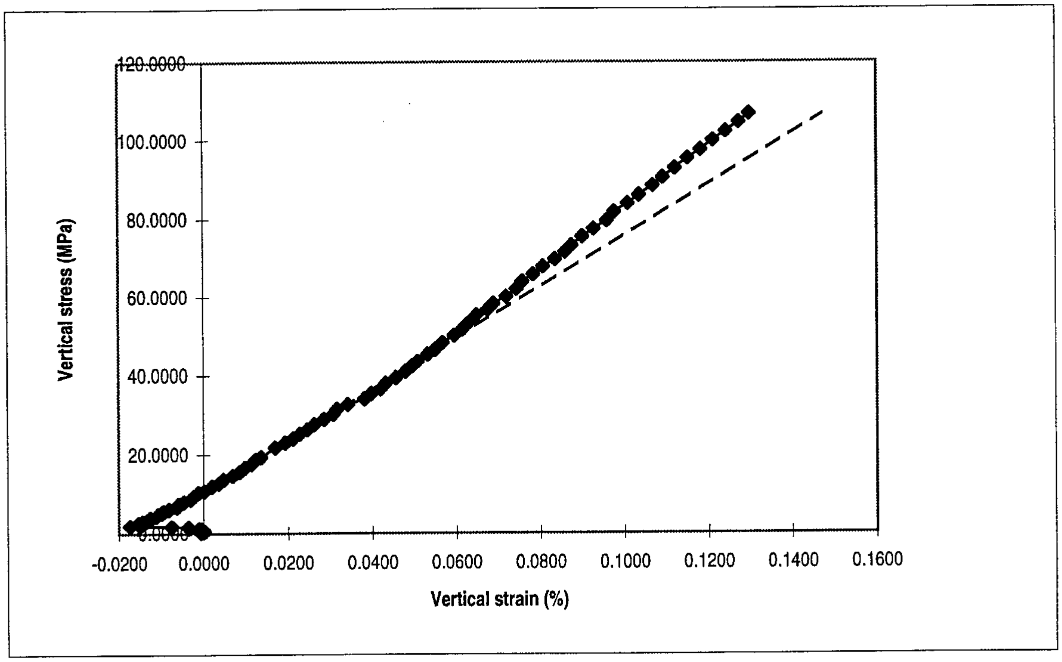
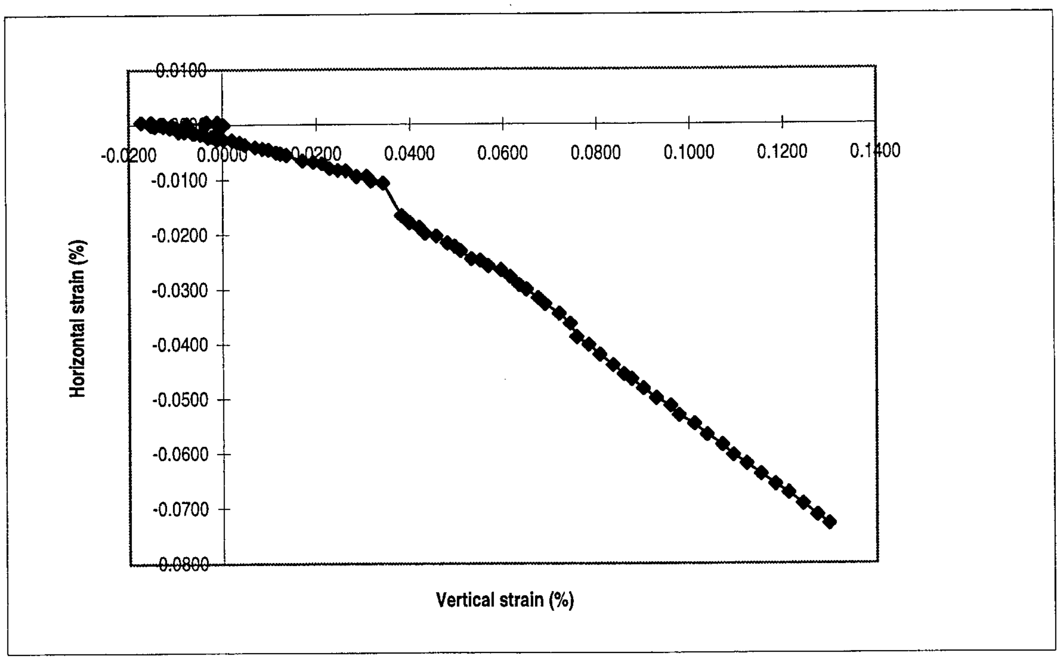
| **WES - TUNNEL CLOSURE EXPERIMENT** | | | | Report No. 923033-13 | Figure No. 10.27 |
| Unconfined Compression Test | | Depth : | 13.6 m | Drawn by PC | Date 28.01.97 |
| Boring : 97/7 | Tube : | | | Checked | NGI |
| Part : 3 | Test : 28 | UCT No. : 379 | | Approved | |

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| Uniaxial compressive strength: | 106.70 MPa |
| Deformation modulus: | 65.39 GPa |
| Poisson's ratio : | 0.241 |

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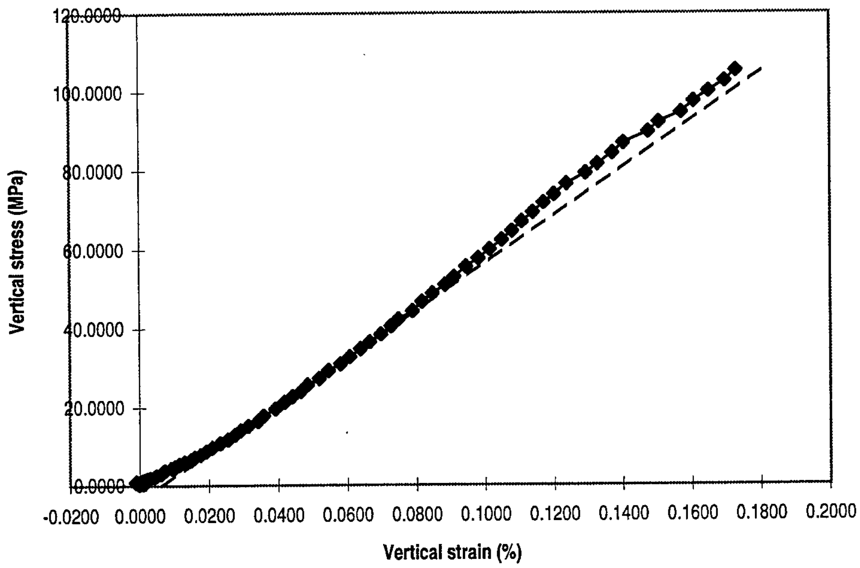
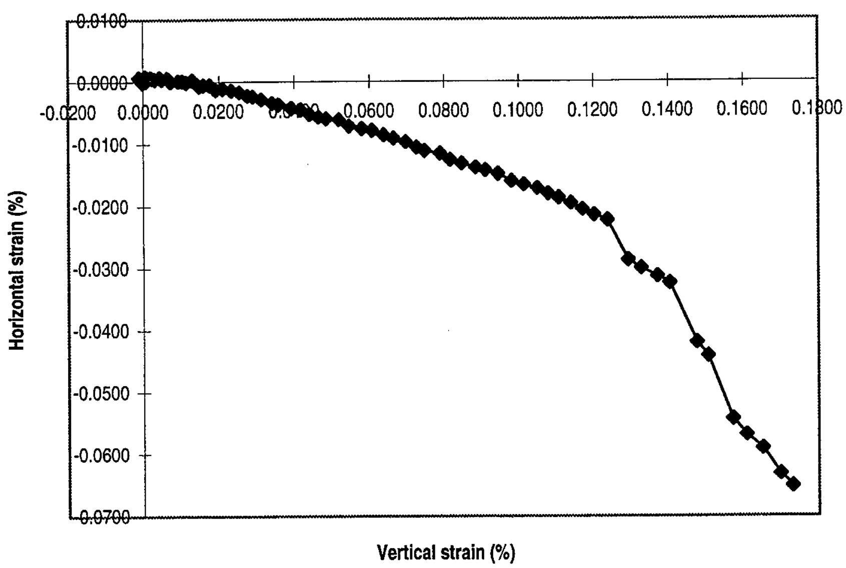
| **WES - TUNNEL CLOSURE EXPERIMENT** | | | Report No. 923033-13 | Figure No. 10.28 |
| Unconfined Compression Test | | Depth : 13.7 m | Drawn by PC | Date 20.02.97 |
| Boring : 97/7 | Tube : | | Checked | NGI |
| Part : 4 | Test : 29 | UCT No. : 380 | Approved | |

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|---|---|
| Uniaxial compressive strength: | 105.20 MPa |
| Deformation modulus: | 60.39 GPa |
| Poisson's ratio : | 0.180 |

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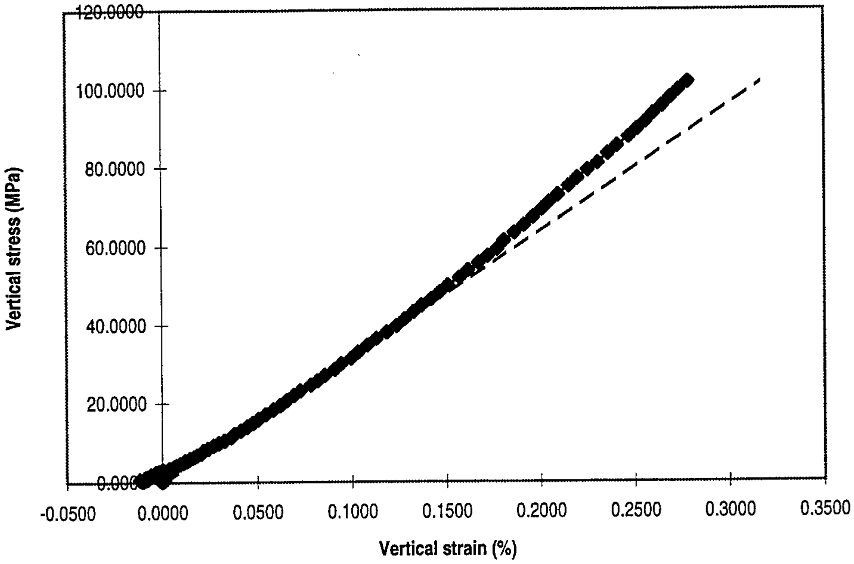
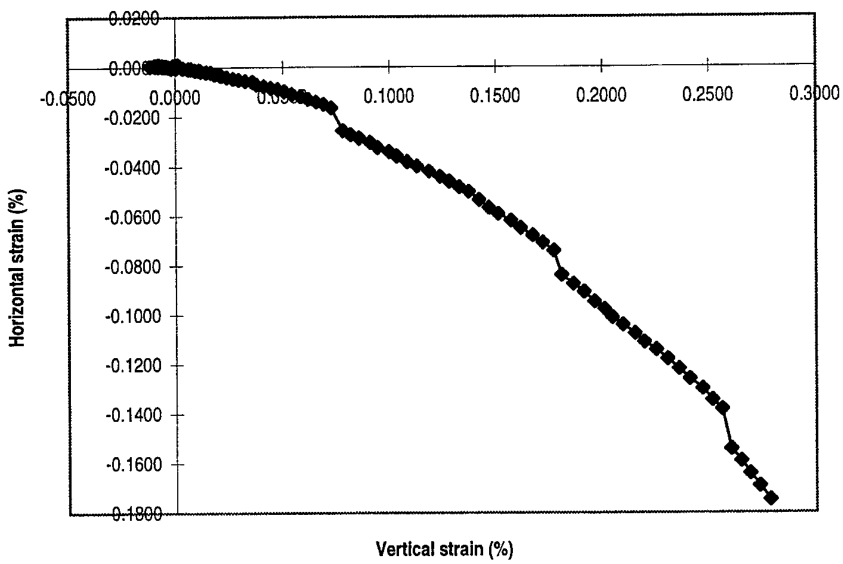
| **WES - TUNNEL CLOSURE EXPERIMENT** | | Report No. 923033-13 | Figure No. 10.29 |
| Unconfined Compression Test | Depth : 13.8 m | Drawn by PC | Date 20.02.97 |
| Boring : 97/7 | Tube : | Checked | NGI |
| Part : 5 | Test : 30 UCT No. : 381 | Approved | |

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|---|---|
| Uniaxial compressive strength: | 101.54 MPa |
| Deformation modulus: | 32.14 GPa |
| Poisson's ratio : | 0.482 |

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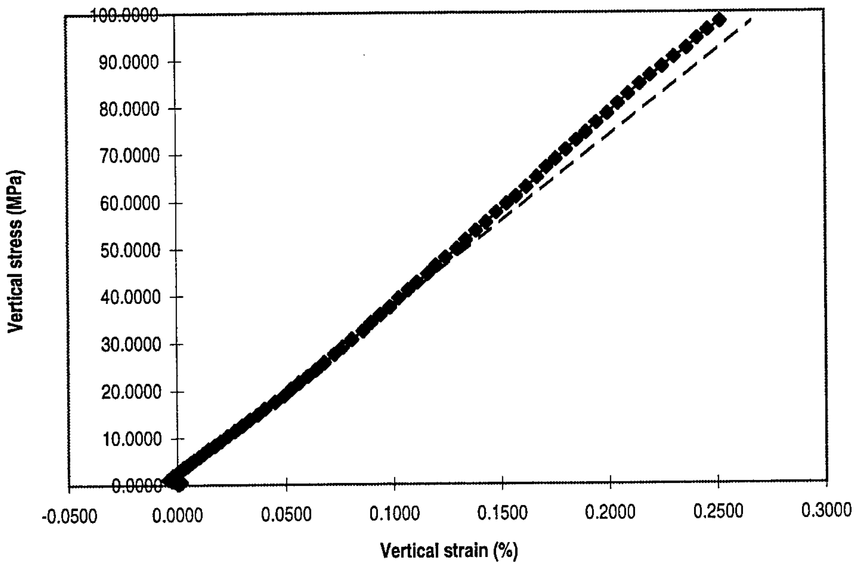
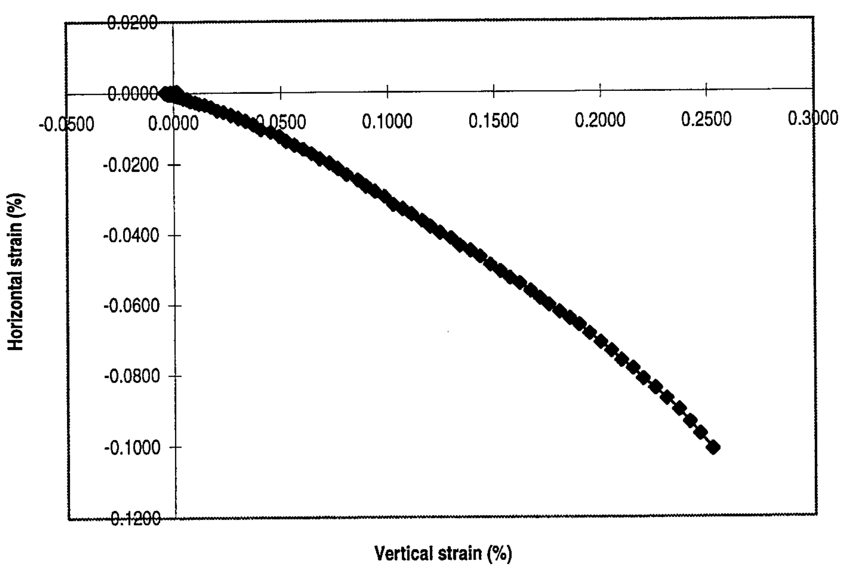
| **WES - TUNNEL CLOSURE EXPERIMENT** | Report No. 923033-13 | Figure No. 10.30 |
| Unconfined Compression Test Depth : 7.0 m | Drawn by PC | Date 24.02.97 |
| Boring : 97/8 Tube : | Checked | NGI |
| Part : 1 Test : 31 UCT No. : 382 | Approved | |

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| Uniaxial compressive strength: | 97.99 MPa |
| Deformation modulus: | 36.17 GPa |
| Poisson's ratio : | 0.323 |

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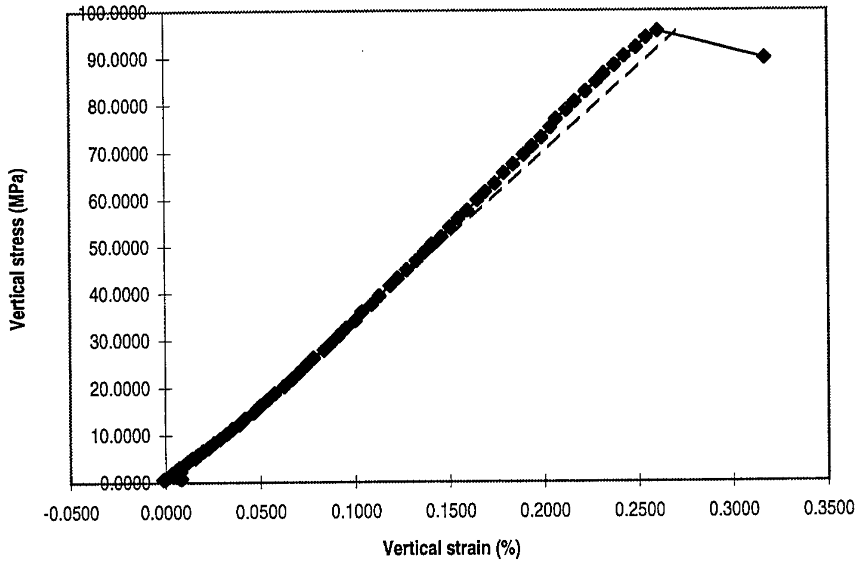
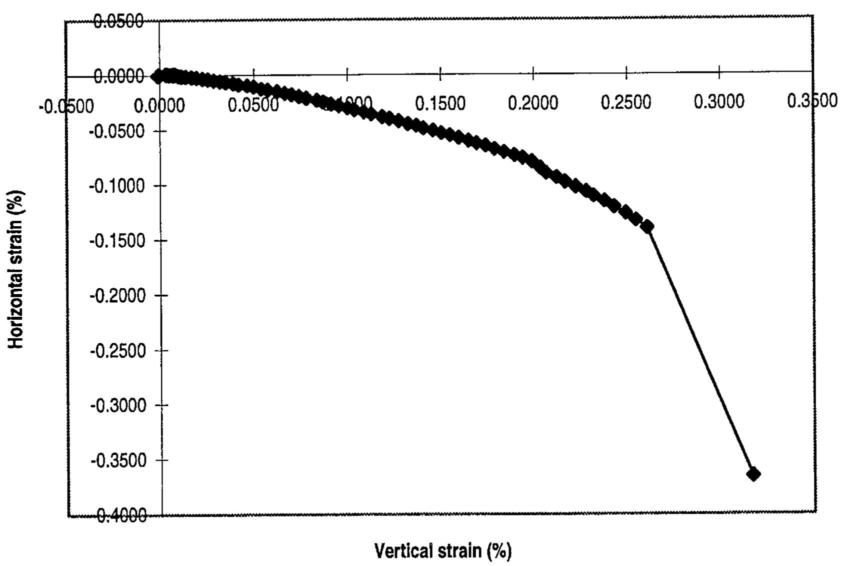
| **WES - TUNNEL CLOSURE EXPERIMENT** | | Report No. 923033-13 | Figure No. 10.31 |
| Unconfined Compression Test | Depth : 7.2 m | Drawn by PC | Date 24.02.97 |
| Boring : 97/8 | Tube : | Checked | NGI |
| Part : 2 | Test : 32 UCT No. : 383 | Approved | |

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|---|---|
| Uniaxial compressive strength: | 95.56 MPa |
| Deformation modulus: | 35.99 GPa |
| Poisson's ratio : | 0.373 |

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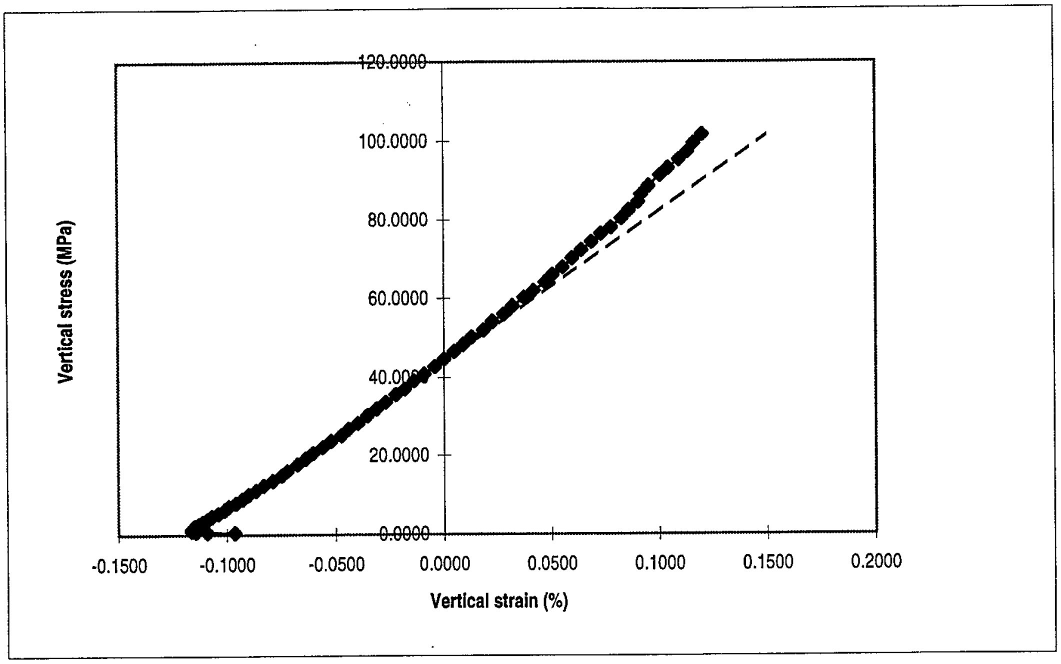
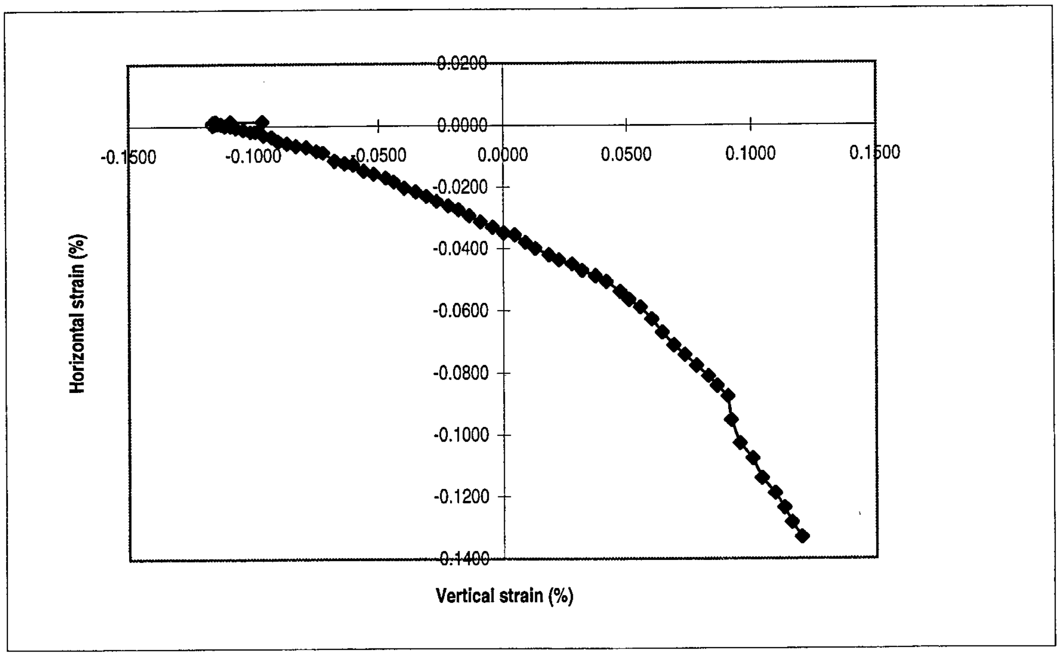
| **WES - TUNNEL CLOSURE EXPERIMENT** | Report No. 923033-13 | Figure No. 10.32 |
| Unconfined Compression Test    Depth : 7.8 m | Drawn by PC | Date 24.02.97 |
| Boring : 97/8    Tube : | Checked | NGI |
| Part : 4    Test : 34    UCT No. : 384 | Approved | |

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| Uniaxial compressive strength: | 101.62 MPa |
| Deformation modulus: | 38.41 GPa |
| Poisson's ratio : | 0.330 |

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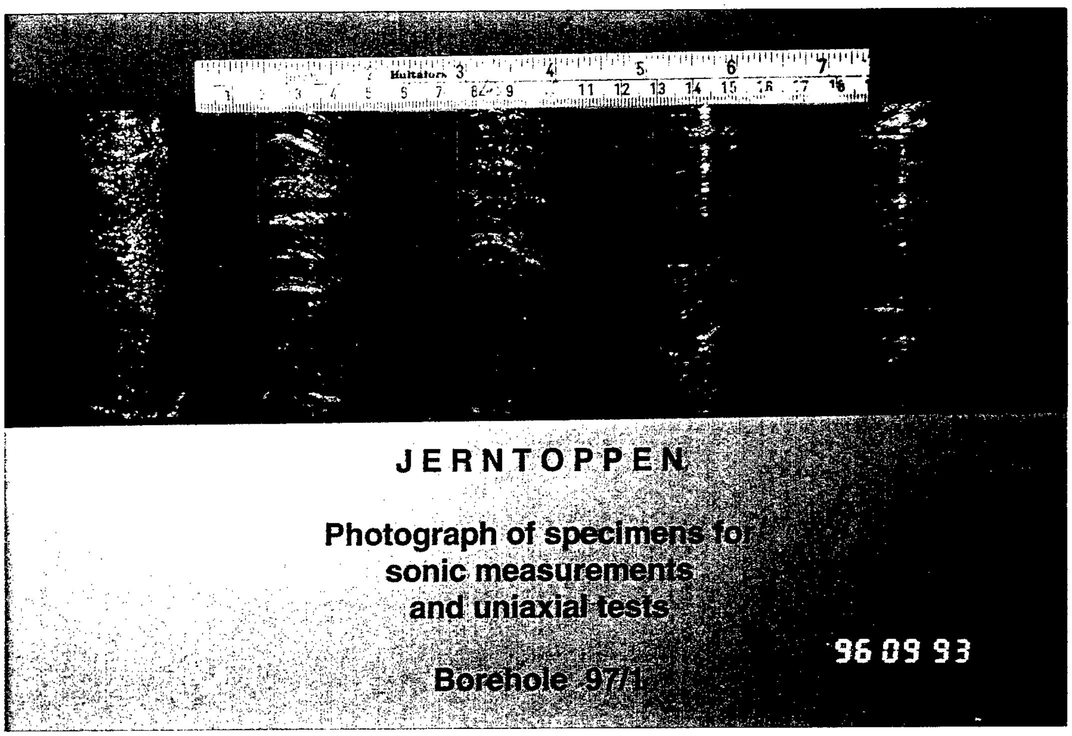
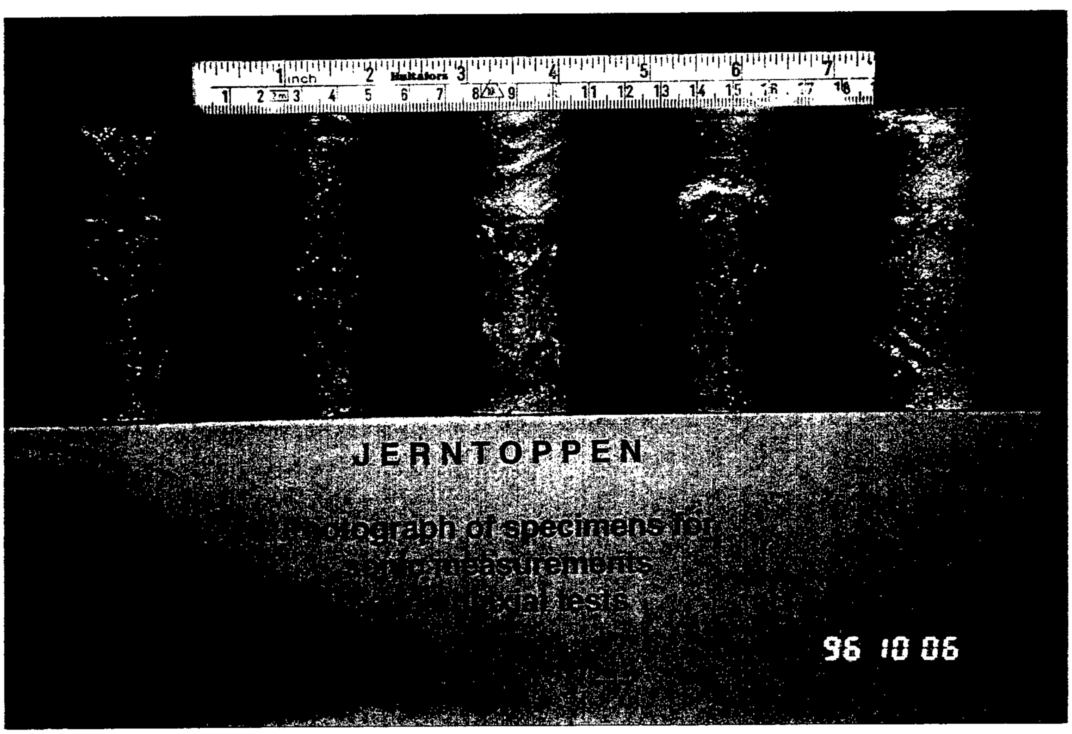
| | | | | Report No. | Figure No. |
|---|---|---|---|---|---|
| **WES - TUNNEL CLOSURE EXPERIMENT** | | | | 923033-13 | 10.33 |
| | | | | Drawn by | Date |
| Unconfined Compression Test | | Depth : | 7.9 m | PC | 24.02.97 |
| Boring : 97/8 | Tube : | | | Checked | |
| Part : 5 | Test : 35 | UCT No. : 386 | | Approved | NGI |

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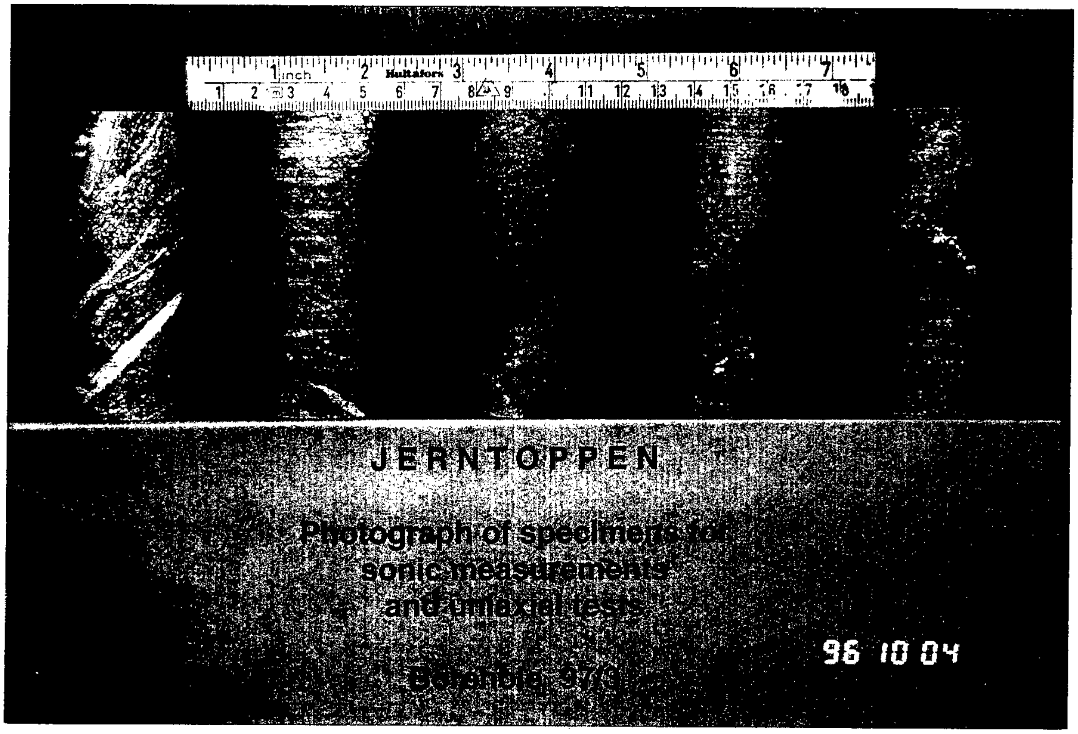
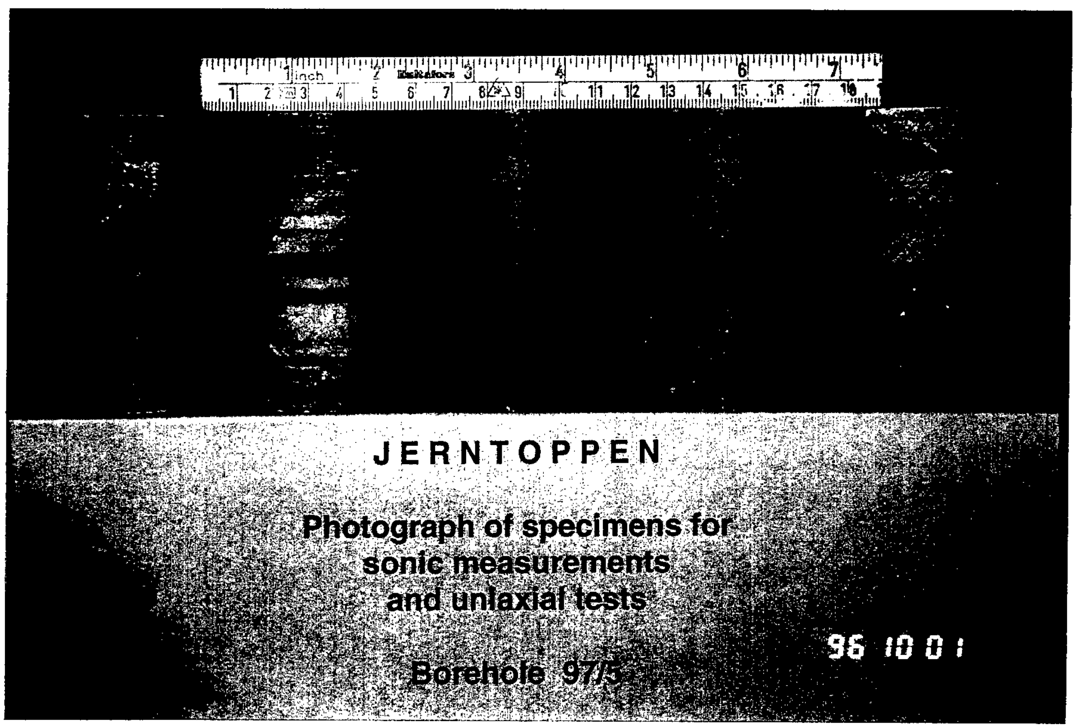
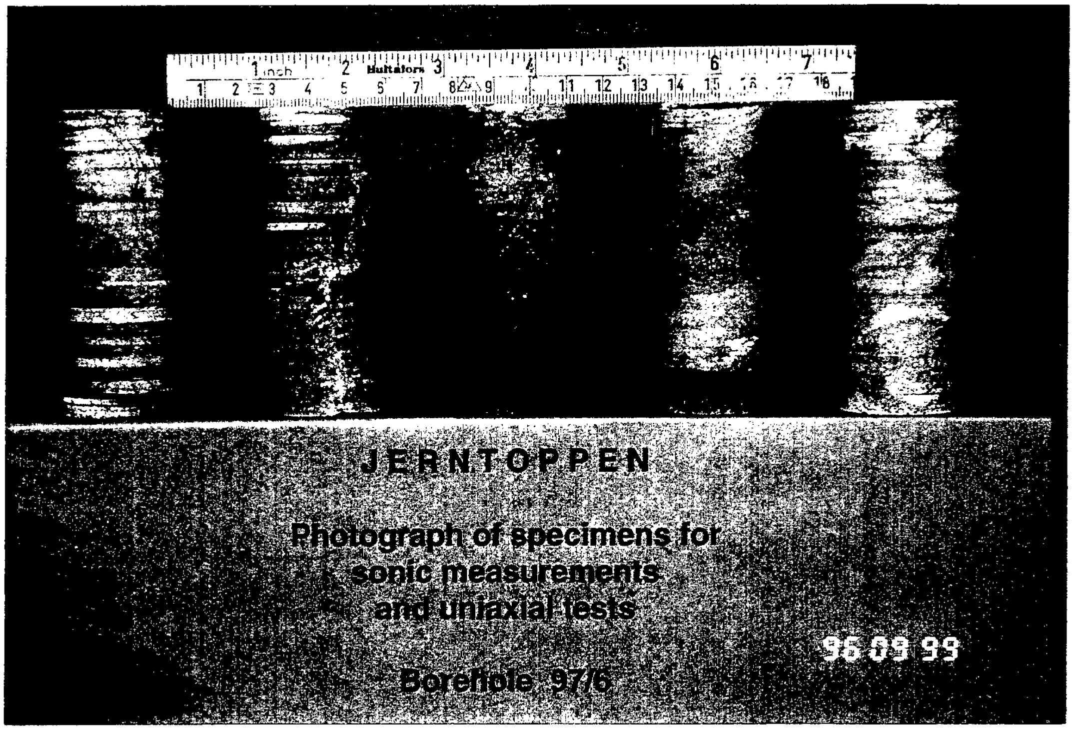
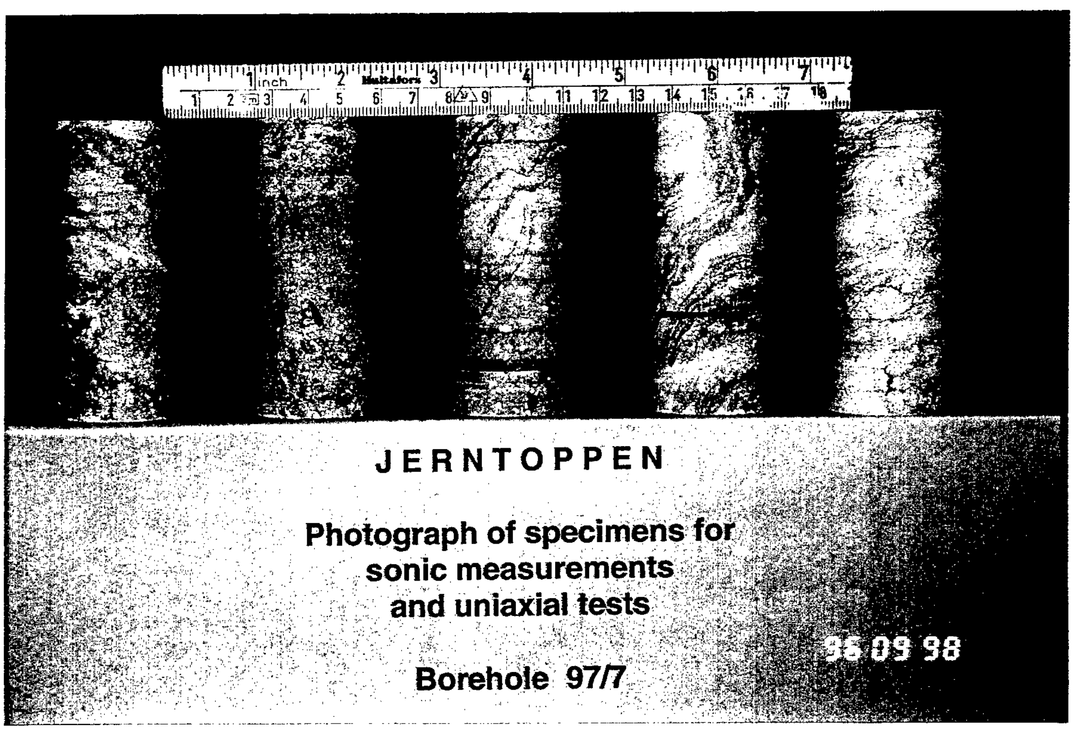
|---|---|---|
| **WES - TUNNEL CLOSURE EXPERIMENT** | Report No.<br>923033-13 | Figure No.<br>11.1 |
| Photos of specimens for laboratory testing<br>Boreholes 97/1 and 97/2 | Drawn by<br>PC | Date<br>97-02-28 |
| | Checked<br>UK | |
| | Approved | NGI |



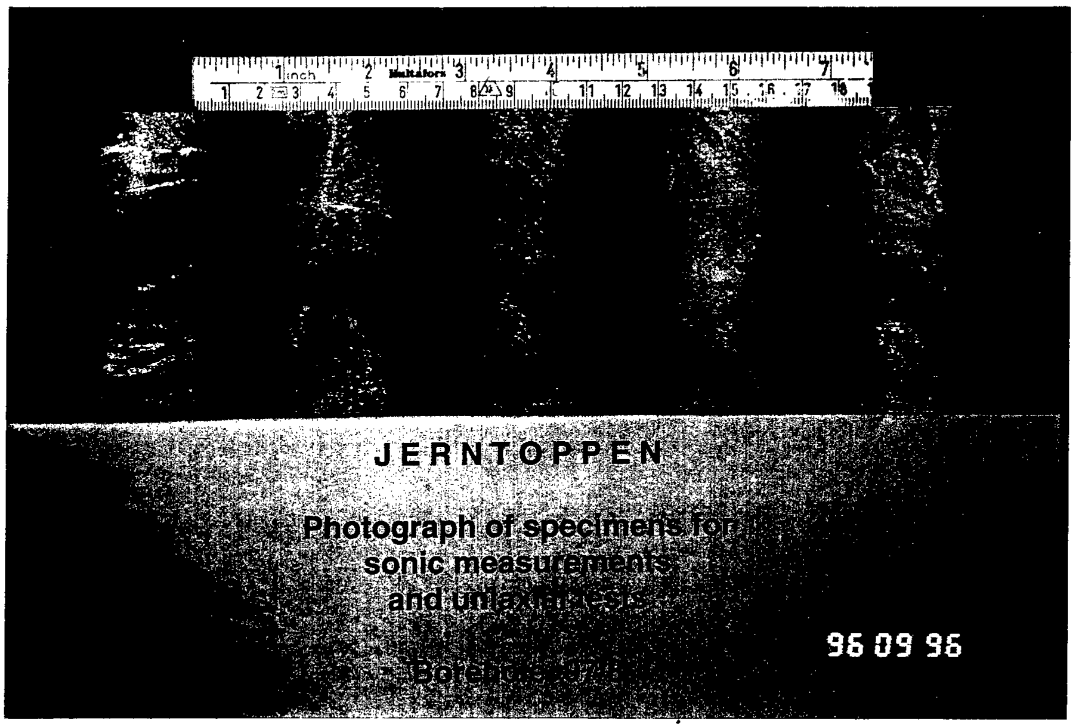




| | | |
|---|---|---|
| **WES - TUNNEL CLOSURE EXPERIMENT** | Report No. 923033-13 | Figure No. 11.2 |
| Photos of specimens for laboratory testing<br>Boreholes 97/3 and 97/5 | Drawn by PC | Date 97-02-28 |
| | Checked VK | NGI |
| | Approved | |




| WES - TUNNEL CLOSURE EXPERIMENT | Report No. 923033-13 | Figure No. 11.3 |
|---|---|---|
| Photos of specimens for laboratory testing<br>Boreholes 97/6 and 97/7 | Drawn by PC | Date 97-02-28 |
| | Checked VK | NGI |
| | Approved | |




| WES - TUNNEL CLOSURE EXPERIMENT | Report No. 923033-13 | Figure No. 11.4 |
|---|---|---|
| Photo of specimens for laboratory testing<br>Borehole 97/8 | Drawn by PC | Date 97-02-28 |
| | Checked VK | NGI |
| | Approved | |

# Kontroll- og referanseside/
# *Review and reference page*

NGI

| **Oppdragsgiver/*Client*** | **Dokument nr/*Document No.*** |
|---|---|
| Waterways Experiment Station | 923033-13 |
| **Kontraktsreferanse/ *Contract reference*** N68171-97-C-9005 | **Dato/*Date*** 8 June 1998 |
| **Dokumenttittel/*Document title*** Tunnel Closure Experiment - 1997 Test Programme. Core Logging and Laboratory Tests on Diamond Drilled Holes at Jerntoppen. | **Distribusjon/*Distribution*** |
| **Prosjektleder/*Project Manager*** Vidar Kveldsvik. | ☐ Fri/*Unlimited* |
| **Utarbeidet av/*Prepared by*** Panayiotis Chryssanthakis, Vidar Kveldsvik | ☒ Begrenset/*Limited* |
| | ☐ Ingen/*None* |

**Emneord/*Keywords***
Core logging, pressure-wave velocity, shear-wave velocity, uniaxial compressive strength, Young's modulus, Poisson's ratio.

| **Land, fylke/*Country, County*** | **Havområde/*Offshore area*** |
|---|---|
| Norway, Finnmark. | |
| **Kommune/*Municipality*** Sørvaranger. | **Feltnavn/*Field name*** |
| **Sted/*Location*** Bjørnevatn, Kirkenes. | **Sted/*Location*** |
| **Kartblad/*Map*** M 711-series. Map 2434 II | **Felt, blokknr./*Field, Block No.*** |
| **UTM-koordinater/*UTM-coordinates*** | |

**Kvalitetssikring i henhold til/*Quality assurance according to* NS-EN ISO9001**

| Kon-trollert av/ *Reviewed by* | Kontrolltype/ *Type of review* | Dokument/*Document* Kontrollert/*Reviewed* | | Revisjon 1/*Revision 1* Kontrollert/*Reviewed* | | Revisjon 2/*Revision 2* Kontrollert/*Reviewed* | |
|---|---|---|---|---|---|---|---|
| | | Dato/*Date* | Sign. | Dato/*Date* | Sign. | Dato/*Date* | Sign. |
| VK | Helhetsvurdering/ *General Evaluation* * | 08-06-98 | VK | | | | |
| | | | | | | | |
| THa | Språk/*Style* | 08-06-98 | THa | | | | |
| | Teknisk/Technical - Skjønn/*Intelligence* | | | | | | |
| | - Total/*Extensive* | | | | | | |
| | - Tverrfaglig/ *Interdisciplinary* | | | | | | |
| THa | Utforming/*Layout* | 08-06-98 | THa | | | | |
| VK | Slutt/*Final* | 08-06-98 | VK | | | | |
| JGS | Kopiering/*Copy quality* | 5/6-98 | JGS. | | | | |
| | | | | | | | |

*** Gjennomlesning av hele rapporten og skjønnsmessig vurdering av innhold og presentasjonsform/**
***On the basis of an overall evaluation of the report, its technical content and form of presentation***

| **Dokument godkjent for utsendelse/ *Document approved for release*** | **Dato/*Date*** 08-06-98 | **Sign.** V Kveldsvik |
|---|---|---|

048. Bra-Trykk AS

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* Reservoarmekanikk og borhullsteknologi
* Grunnundersøkelser og laboratorieundersøkelser
* Modell- og feltforsøk
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* *Avalanches, landslides and safety measures*
* *Environmental geotechnical engineering*
* *Petroleum reservoir mechanics and borehole technology*
* *Site investigations and laboratory testing*
* *Model and field testing*
* *Field instrumentation and performance evaluation*